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GEOSYNCHRONOUS PLATFORM DEFINITION STUDY

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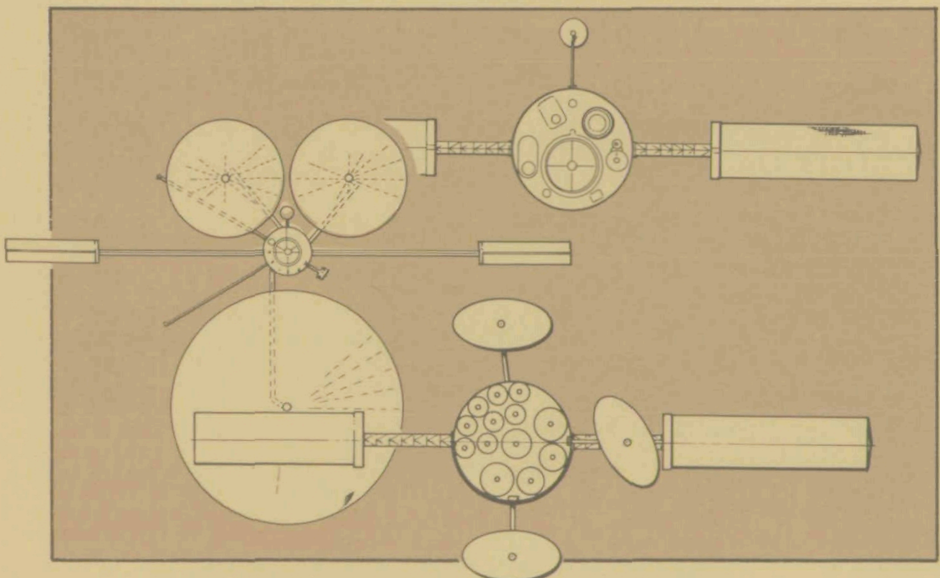
Volume VII

GEOSYNCHRONOUS TRANSPORTATION REQUIREMENTS



JUNE 1973

Space Division
Rockwell International

12214 Lakewood Boulevard
Downey, California 90241

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Volume VII

GEOSYNCHRONOUS TRANSPORTATION REQUIREMENTS

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JUNE 1973

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FOREWORD

The Geosynchronous Platform Definition Study was a pre-Phase A analysis conducted by the Space Division of Rockwell International Corporation (Rockwell) under Contract NAS9-12909 for the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration. The study explores the scope of geosynchronous traffic, the needs and benefits of multifunction space platforms, transportation system interfaces, and the definition of representative platform conceptual designs. The work was administered under the technical direction of Mr. David Brown (Telephone 713-483-6321) of the Program Planning Office/Future Programs Division of the Lyndon B. Johnson Space Center.

This report consists of the following seven volumes:

Volume I - Executive Summary	SD 73-SA-0036-1
Volume II - Overall Study Summary	SD 73-SA-0036-2
Volume III - Geosynchronous Mission Characteristics	SD 73-SA-0036-3
Volume IV, Part 1 - Traffic Analysis and System Requirements for the Baseline Traffic Model	SD 73-SA-0036-4 Part 1
Volume IV, Part 2 - Traffic Analysis and System Requirements for the New Traffic Model	SD 73-SA-0036-4 Part 2
Volume V - Geosynchronous Platform Synthesis	SD 73-SA-0036-5
Volume VI - Geosynchronous Program Evaluation and Evaluation	SD 73-SA-0036-6
Volume VII - Geosynchronous Transportation Requirements	SD 73-SA-0036-7

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ABBREVIATIONS

ASCS	Attitude stabilization and control system
ATS	Applications Technology Satellite
CCD	Charge coupled device
CCIR	Consultative Committee for International Radio
CM	Crew module
C/N	Carrier-to-noise ratio
COMM	Communications
Comsat	Communications Satellite
CSM	Common support module
DMS	Data management subsystem
Domsat	Domestic Communications Satellite
ECS	Environmental control subsystem
EIRP	Effective isotropic radiated power
EPS	Electrical power subsystem
FDMA	Frequency division multiplexing
FM	Frequency modulation
GEOPAUSE	Geodetic satellite in polar geosynchronous orbit
Geoseps	Geosynchronous solar electric propulsion stage
Intelsat	International Communication Satellite
IPACS	Integrated power and attitude control system
Mersat	Metrology and Earth Observations Satellite
Navsat	Navigation and Traffic Control Satellite

OTS	Orbital transportation system
PCM	Pulse code modulation
PSK	Phase shift keying
RCS	Reaction control subsystem
RSU	Remote service unit
SATA	Small Application Technology Satellite
SEP	Solar electric propulsion
SGLS	Space-ground link subsystem (part of U.S. Air Force Satellite Control Facility)
SNR	Signal-to-noise ratio
SSM	Spares storage module
STDN	Spaceflight tracking and data network
STS	Space transportation system
TDMA	Time division multiple access
TDRS	Tracking and Data Relay Satellite
TPS	Thermal protection subsystem
TT&C	Tracking, telemetry and command
UHF	Ultra high frequency
VHF	Very high frequency
WARC	World Administrative Radio Conference
XMTR	Transmitter

1.0 INTRODUCTION

This volume presents the analyses and trade studies conducted to define the interfaces between geosynchronous platforms and the space transportation system (STS). Mission timelines are synthesized for both manned and unmanned placement and servicing operations. Physical, operational, and functional interfaces between platforms and the space shuttle and tug are derived from the timelines. Where interface incompatibilities exist, alternate approaches are evaluated and a preferred approach is defined.

An evaluation of the adaptation of the Solar Electric Propulsion (SEP) stage for geosynchronous operations is presented. A comparison of geosynchronous platform programs with and without the SEP stage in the transportation system is developed.

2.0 SUMMARY

The purpose of the Geosynchronous Platform Definition Study was to define requirements, establish the feasibility of, and describe the programmatics for geosynchronous platforms that would (1) have the equivalent performance capability of the satellite inventories of two different traffic models, and (2) be compatible with both manned and unmanned on-orbit servicing operations. The analyses associated with these tasks are reported in Volumes III through VI. This volume, Volume VII, presents the analyses and trade studies that were conducted to determine the preferred concepts for establishing interfaces between the space transportation system and platforms.

Because of the similarity among the platforms that were synthesized, interface analyses were required for only one configuration. The significant differences in the interfaces were primarily functions of the missions and the operational modes. The five modes selected for analysis were the following:

Unmanned Modes	Manned Modes
Placement	Servicing
Servicing	Placement & servicing
Placement & servicing	

The space transportation system elements considered in the interface analyses were the space shuttle, single and dual stage tugs, remote servicing units, and a crew module. Also, the solar electric propulsion stage was evaluated for applicability to platform programs.

Representative missions, including delta-V requirements and event timelines, were synthesized for each operational mode. Each major mission event was analyzed to identify potential physical, operational, and/or functional interfaces between the transportation system elements and the platform. Among the interfaces analyzed were the following:

Physical:	Structural attachment; electrical/electronic connections; crew transfer provisions
Operational:	Rendezvous, predocking assessment, docking, separation; activation/checkout/deactivation servicing; data management
Functional:	Power, data management, life support

The high technology tug, with the payload support capabilities defined in the Tug Operations and Payload Support Study (Reference 2-1), was used as the baseline unmanned tug. It was assumed that the manned tug would have essentially the same payload support capability as the unmanned tug except that a docking port compatible with the five-foot diameter ring of the shuttle would replace the probe and drogue configuration.

The space shuttle payload support capability used as the baseline in the analyses conformed to that in MSC 06900, Space Shuttle Baseline Accommodation for payloads (Reference 2-2).

In most cases, the baseline concepts for the interfaces between the transportation system and the platform were compatible. Table 2.0-1 lists the few incompatible interfaces, as well as the options evaluated, the preferred concept, and the rationale for its selection. The only direct platform interface with the space shuttle was in the combination manned servicing-placement mission. A structural cradle/retention mechanism and electrical umbilical interface was required. However, the mechanization could be the same as that required for other multi-payload shuttle missions.

The evaluation of the applicability of the solar electric propulsion (SEP) stage to the geosynchronous platform was based upon a comparison of ten-year programs with and without the SEP. Depending upon which traffic models were used (baseline or new), a savings of from \$50 million to \$200 million could be realized over a ten-year period with a SEP stage. Also, it offers payload delivery capabilities in excess of 10,000 pounds, and its long mission life makes possible servicing missions for widely-spaced platforms.

There are disadvantages associated with the use of the SEP stage. Payload exchange operations are required between the tug and the SEP stage in intermediate orbits. It is impractical to operate the SEP stage between the shuttle and geosynchronous orbits. Mission durations would be several hundred days and for an appreciable period of that time, the SEP stage would be operating in the Van Allen belt. Intolerable degradation of the SEP solar arrays would result. Long trip times, even from intermediate orbits (87 to 153 days) precludes manned missions. Also, at least limited mission control support would be required for these long durations adding further complexities to program operations.

Table 2.0-1. Preferred Approaches for Incompatible Interfaces of Baseline STS and Platform

Interface	Baseline Concept	Options	Selection	Rationale
RF communications to ground	No interface	1. Service unit to gnd 2. Tug comm. link to gnd 3. Tug data mgmt. to gnd	No. 2	Minimum impact on integrated transportation system.
Energy	140 kw hr available; 152 kw hr required	1. Add fuel cell reactants 2. Add batteries	No. 1	Required additional reactants (8.2 lb) is lightest, least volume concept
Electrical inter-connection to shuttle	Copper path	1. Separate platform um-bilical 2. Copper path through tug 3. Through tug subsystems	No. 3	Platform-tug interface required during orbit transfer and servicing operations; no justifi-cation for second interface
OTS-platform docking mechanism	Probe & drogue	1. Shuttle compatible 2. 7-foot ring with 5-foot adapter	No. 2	Large diameter required for auto-remote servicing; adapter required for manned tug compatibility with shuttle
Life support functions	No interface	1. Integral to platform 2. Temporary provisions from tug	No. 2	Long duration between activations of critical life support functions precludes integral concept

3.0 SELECTED PLATFORM CONFIGURATION AND MODES

The baseline definition of the platform used in the interface analyses is described in Section 3-1. The Region IV Domsat platform synthesized to meet the requirements of the new traffic model was selected as the representative configuration.

Five operational modes involving both manned and unmanned placement and servicing missions are defined in Section 3.2. These modes are the basis for the subsequent (Section 4.0) development of mission timelines, identification of mission events, and identification of interface functions between the space transportation system and the platform.

The characteristics of the space shuttle and the tug that were assumed in the interface analyses are presented in Section 3.3. Both single (unmanned) and dual (manned) tug configurations are baselined. The crew module and the remote servicing unit which were defined in Section 5.4 of Volume IV - Part 1, are also considered as part of the Orbit Transportation System (OTS). Use of the solar electric propulsion stage as an OTS is discussed in Section 6.0.

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3.1 REPRESENTATIVE PLATFORM DEFINITION

Rather than selecting a few of the platforms synthesized during the basic study and evaluating each set of interfaces, it became apparent that the particular platform(s) chosen for the interface analysis was not significant. Use of the same support systems module for all platforms, plus the adaptability of the platform configuration for both manned and auto-remote servicing modes, precluded any unique differences between various platforms and the transportation system. The significant differences are dependent upon the mission profile and the servicing modes rather than the specific platform used in the analysis.

In this section, the representative platform used in the analysis is defined. The operational modes analyzed in the study are defined in Section 3.2.

The high percentage and relative complexity of data relay platforms in the inventories of the two traffic models indicated that one of this type would be the most representative. The Region IV Domsat platform for the new traffic model was selected for the analyses because it is considered to be the most complex data relay platform. Figure 3.1-1 illustrates the platform. A full complement of C-, K_{LO}-, and K_{HI}-band transponder is included. Foldout appendages are required for the C-band shaped antennas. The platform weighs in excess of 4000 pounds and requires more than 1600 watts of power. The common support module, which is defined in Section 3.1 of Volume V, contains a full complement of subsystem assemblies including the 50 Mbps TT&C capability and four RCS quads.

Although the Domsat platform described above was used as the model for transportation system-platform interface analyses all the platforms synthesized in the study were considered in the evaluations. For example, some platforms weighed in excess of 8000 pounds. An evaluation of the structural interfaces of this size of platform is required in addition to the basic analysis conducted with the Domsat platform.

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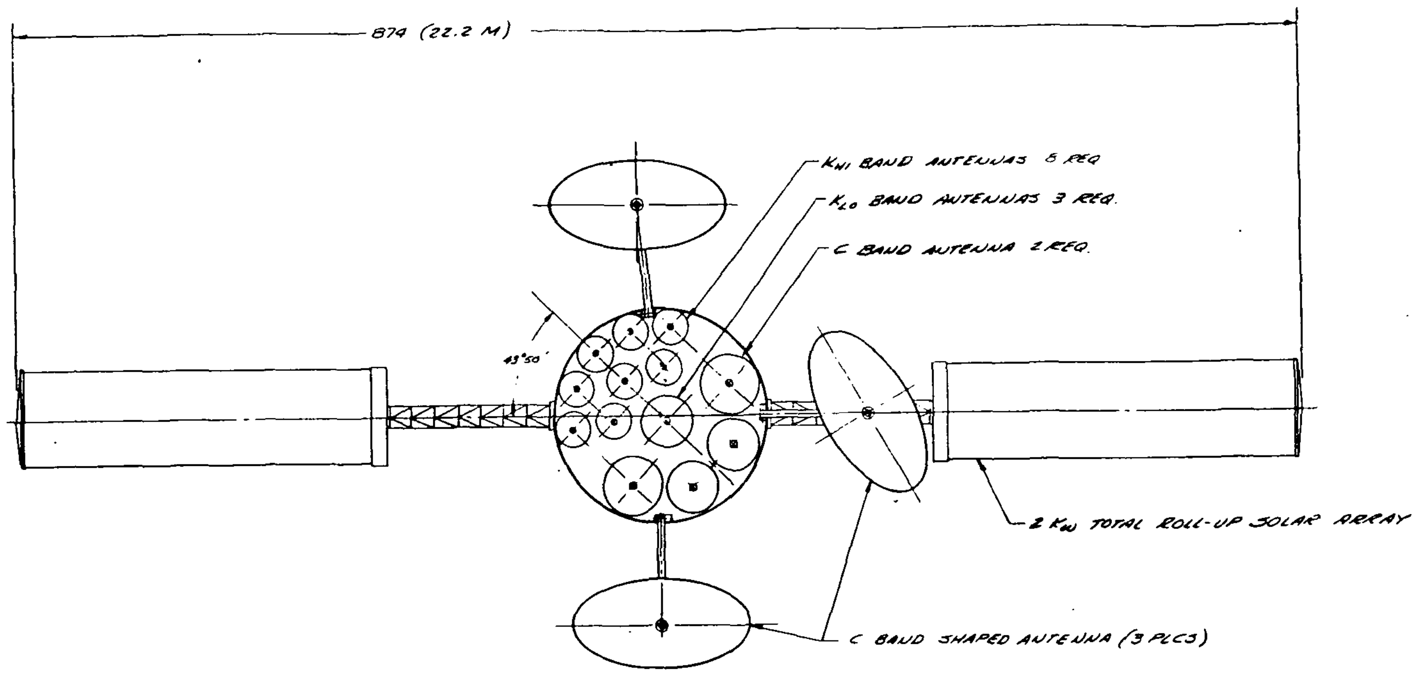

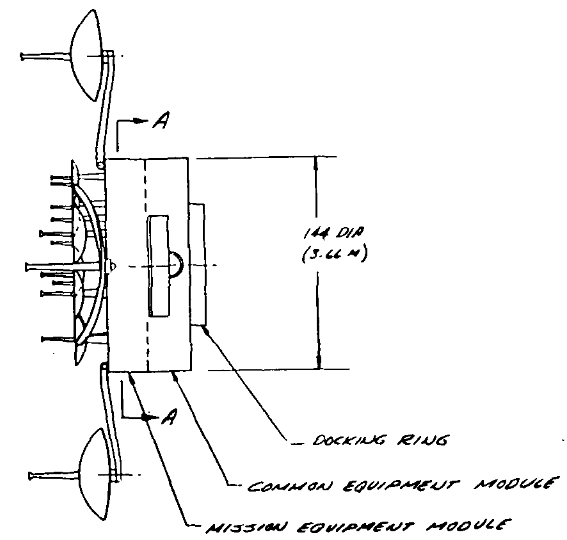

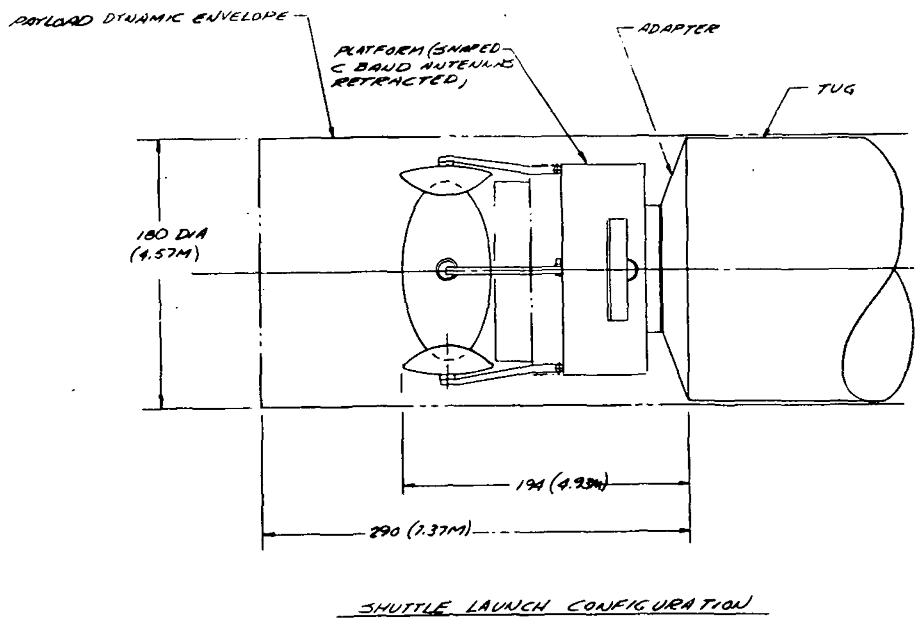

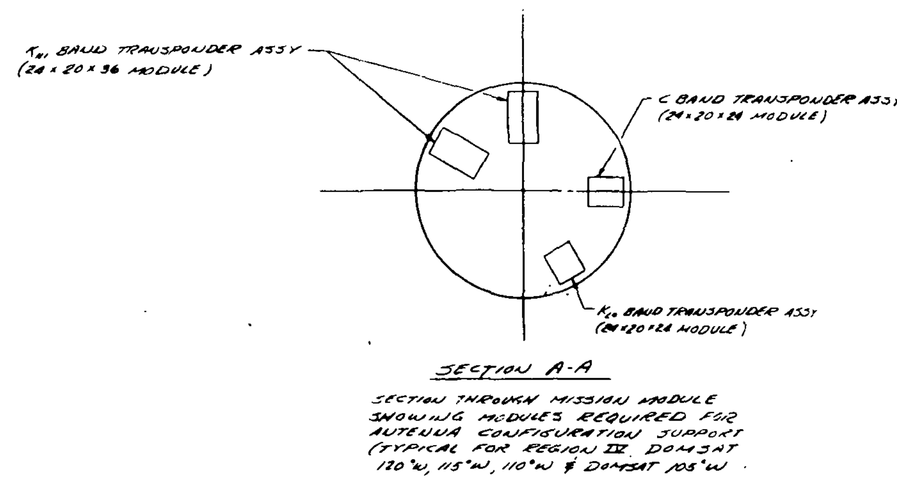

	WEIGHT (LB)	POWER (WATTS)
MISSION EQUIPMENT	2016	1385
COMMON SUPPORT MODULE	1989	218
TOTAL	4005	1603

Figure 3.1-1. Baseline Platform Configuration

3.2 OPERATION MODES

Five operational modes or missions were selected for analysis and evaluation of the transportation system interfaces and requirements. They are derived from the placement and servicing of the geosynchronous platform in its operational orbit by unmanned (auto-remote) and manned orbital transport systems. The modes selected are:

1. Platform orbital placement
2. Platform auto-remote servicing
3. Platform placement and auto-remote servicing
4. Platform manned servicing
5. Platform placement and manned servicing

The transportation elements utilized are: (1) the space shuttle to deliver and retrieve its payload to and from low earth orbit and (2) the reusable tug that operates between low earth orbit and the desired geosynchronous orbit. The shuttle payload configurations for each of the operational modes, which consist of combintations of the tug, platforms, and servicing units, are presented in Figure 3.2-1. The utilization of the solar electric propulsion vehicle as an interorbital transportation system vehicle is discussed in Section 6.0 of this volume.

PLATFORM ORBITAL PLACEMENT

The placement mission entails the delivery of the geosynchronous platform to its operational orbit and the support to the platform from the tug during transit, activation, checkout, and placement operations. No servicing or repair is planned for this mission.

After the placement operation is complete, the tug rendezvouses in close proximity with the shuttle in a 170-nm circular orbit. The shuttle orbiter performs the terminal rendezvous, retrieves the tug, and deorbits.

PLATFORM AUTO-REMOTE SERVICING

The platform's auto-remote servicing mission involves the delivery and docking of a remote servicing unit to platforms in geosynchronous orbit for pre-planned servicing operations. The tug performs the servicing mission functions of delivery, docking, and support to the servicing unit and the platform while attached.

PLATFORM PLACEMENT/AUTO-REMOTE SERVICING

This mission combines the mission objectives of platform placement and auto-remote servicing of platforms already on-orbit.

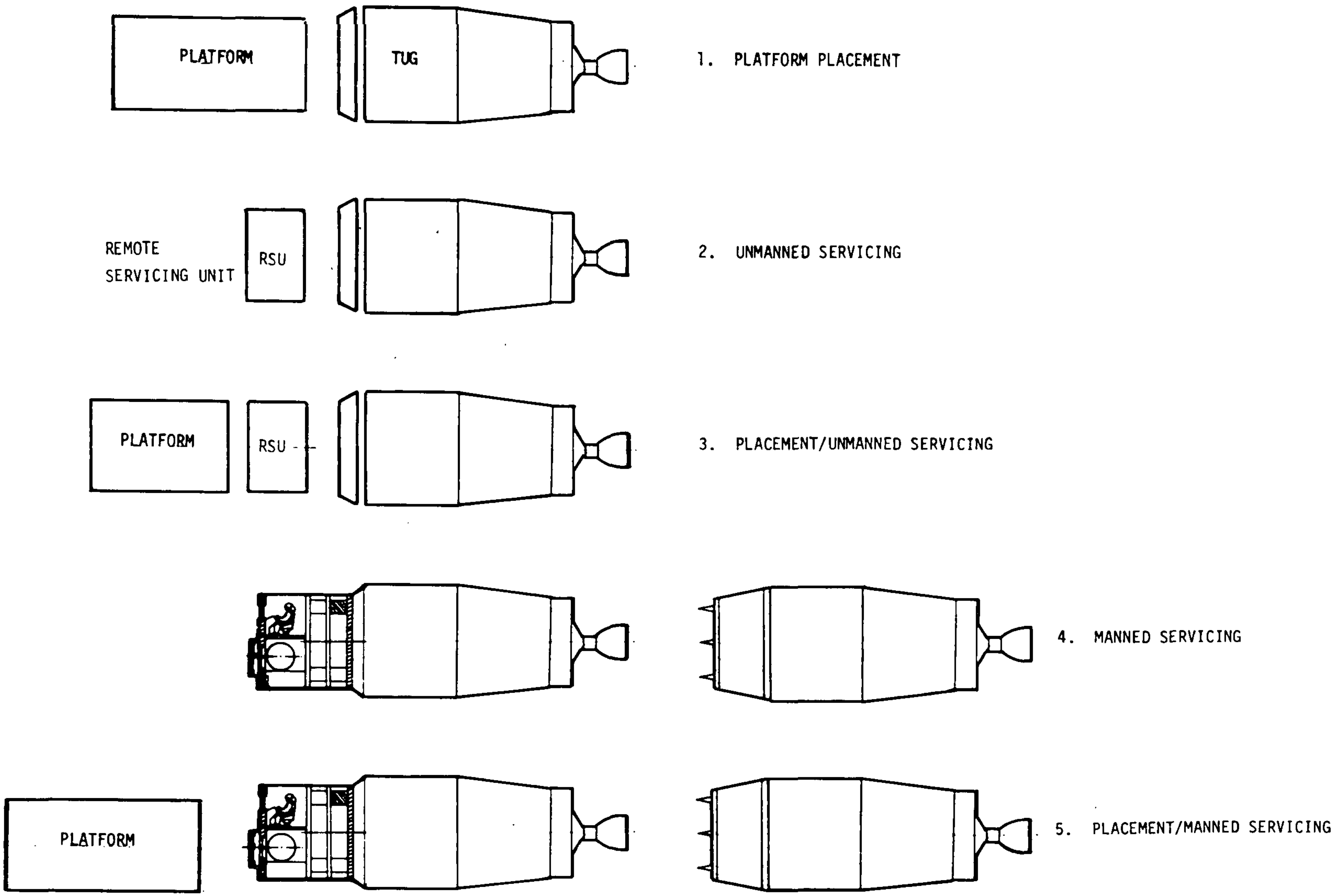

Figure 3.2-1. Shuttle Payload Placement and Servicing

PLATFORM MANNED SERVICING

The objectives of this mission are the same as that of the auto-remote servicing mission. The technique is significantly different, and the flexibility in the activities during the operation is greatly increased because of the on-site presence of man. The manned servicing mission requires a two-tug configuration to transport a crew module, which was estimated to weigh approximately 6000 pounds (see Section 5.4, Volume IV, Part 1), to and from geosynchronous orbit. For purposes of this study, the dual tug concept was assumed to be two high technology tug stages assembled in a tandem configuration. Similarly, dual shuttle launch and on orbit assembly operations are required because of both payload weights and shuttle cargo bay length limitations.

PLATFORM PLACEMENT AND MANNED SERVICING

This mission combines the objectives of manned servicing of platforms already on-orbit and the initial emplacement of platforms, which could be activated and initialized in a man attendant mode.

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3.3 BASELINE SPACE TRANSPORTATION SYSTEM ELEMENTS

The baseline interface characteristics of the space transportation system elements are summarized in this section. The space shuttle characteristics were extracted from MSC 06900 Space Shuttle Baseline Accommodations for Payloads. The characteristics of the tug stage were extracted from MA-04 Tug Operations and Payload Support Study, Final Report (Reference 2-1). It was assumed that the crew module of the manned tug configuration would include all provisions required for the crew support functions. Thus, the manned tug configuration has the same payload support capability as the unmanned tug configuration.

SPACE SHUTTLE

Delivery of a payload to a 160 n mi, 28.5-degree inclination circular orbit and retrieval of a payload from a 170 n mi, in-plane, (28.5 degrees inclination) circular orbit on the same flight is the baseline geosynchronous logistics mission of the shuttle that is used in this study. The definition of other shuttle payload support capabilities and environments presented to payloads are presented below. Unless otherwise stated all values are maximum.

<u>Support Capabilities</u>

Structural/Mechanical

Payload weight	
Launch	65,000 pounds
Landing	40,000 pounds nominal, up to 65,000 pounds with reduced safety factors
Payload envelope	15-foot diameter by 60-foot length
Docking port diameter	5 feet (nominal)
Docking parameters	
Lateral misalignment	±0.5 feet
Angular misalignment	±5.0 degrees
Roll misalignment	±7.0 degrees
Closing velocity	0.5 fps
Payload alignment in bay	0.5 degrees

Electrical power		
Voltage	28 vdc nominal	
Load	Shuttle orbital operation periods	
	1000 watts average	
	1500 watts peak	
	Shuttle on-orbit coast periods	
	3000 watts average	
	6000 watts peak	
Energy	50 kwh dedicated	
Source	Redundant dc buses in payload bay	
Guidance and Navigation		
Orbit navigation accuracies	STDN	1000 feet
	Star/horizon	4000 feet
	Ground/beacon	1000 feet
	Horizon/beacon	700 feet
	TDRS	300 to 1000 feet
	Landmark	2000 feet
Rendezvous range	300 n mi with cooperative target	
Attitude pointing accuracy	0.5 degree	
Deadband (nominal)	0.5 degree, 0.1 degree	
Data Management (Time shared)		
Computation	10,000 32-bit words	
Data transfer	25,000 bps via data bus	
Data downlink	256,000 bps digital data, TV, and voice	
Data uplink	2000 bps	
Environmental Control/Life Support		
Personnel accommodations	42 man-days	
	4 men, 7 days (nominal)	
Waste management	Water storage, 24 hours	
Active thermal control	Orbiter operations	5200 Btu/hr
	On-orbit coast	TDB

Shuttle Environment

Payload Bay Environment

Acoustic	Less than 145 dB overall		
Vibration	≤ launch vehicle payload environment		
Acceleration (g's)	X	Y	Z
Launch	1.5 ± 1.0	+0.25 ± 0.5	+0.25 ± 0.5
Maximum boost	3.0 ∓ 0.25	∓0.2 ∓ 0.25	∓0.3 ∓ 0.25
Entry	-1.0	∓0.5 ∓ 0.25	-3.0 ∓ 0.5

Thermal	Minimum (deg F)	Maximum (deg F)
*Prelaunch	+40	+120
Launch	+40	+150
On-orbit	-100	+150
*Entry + post-landing	-100	+200

*GSE conditional air available.

REUSABLE TUG

The tug has two configurations. The first configuration is the high technology tug that is used to support the unmanned mission. The second configuration that supports the manned missions consists of two man-rated tug stages assembled in tandem and a crew module.

The tugs and their payloads are delivered by the shuttle to a 160 n mi circular orbit at a 28.5-degree inclination. The tugs deliver their payloads (platform, service unit, or both) to geosynchronous orbit, support the activation of a platform, and/or the servicing of up to three on-orbit platforms. After completion of the geosynchronous orbit operation, the tugs return to within 300 nautical miles of a stationkeeping shuttle in a 170 n mi circular orbit at 28.5 degrees inclination.

The unmmaned tug provides the following support capability to its payload. Unless otherwise stated all values are maximum.

Mechanical/Structural

Docking and separation	Probe and drogue
Electrical connector	Within 37-inch radius of tug centerline

Operational Interfaces

Deployment accuracy and imparted forces	Within ±25 n mi altitude ± 0.1 degree inclination Tipoff acceleration: 0.1 g Tipoff rate: 1 degree/second

Attitude stability and pointing accuracies	Stability: 0.1 degree/second Pointing: 0.2 degree
Rendezvous accuracy	50 n mi (autonomous or ground track)
Terminal rendezvous	0.1 meter and 0.1 degree accuracy (laser radar)
Docking method	TV or laser radar
Satellite inspection	TV

Functional Interfaces

Power	700 watts, 40 kw hours
RF communication	None
Hardwire interface	Copper path from payload interface to tug/shuttle interface

The manned tug provides the following additional and/or modified support capability and interface characteristics to that provided by the unmanned tug.

Mechanical/Structural

Docking and separation	Five-foot shuttle compatible docking port
Electrical connector	General purpose for payload adaptation

Operational Interfaces

Docking	Visual by crew and laser radar
Satellite inspection	Visual by crew and TV

Functional Interface

Power	700 watts, 40 kw hours
Communication	Voice, low data/command rates, and TV

4.0 INTERFACE ANALYSES

Representative mission timelines for the five operational modes are developed in Section 4.1. Nominal delta-V requirements are defined, and mission events are identified.

Each major mission event is examined to establish potential interface requirements between the transportation system and the platform. The interfaces are sub-divided into three categories.

1. Physical interfaces: Includes structrual/mechanical interconnects (docking parts, electrical connectors).

2. Operational interfaces: Consists of the potential impacts on one element that could result from the unique activities of another (appendage deployment, attitude maneuver, rendezvous, etc.).

3. Functional interfaces: Consists of direct active and passive support of the platform by the transportation system equipment (power, communications, data management, etc.). The interfaces are identified for both platform-tug and platform-space shuttle configurations.

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4.1 MISSION AND OPERATIONS ANALYSIS

This section defines the operational timelines for placing in orbit and servicing the selected geosynchronous platform, and also presents supporting parametric orbital data developed to a level of detail in which the key interfaces between the space transportation system and the selected geosynchronous platform can be identified. This section first defines basic trajectory data which is an amplification of the data presented in Section 3.3 of Volume III. Payload delivery and servicing timelines are then defined.

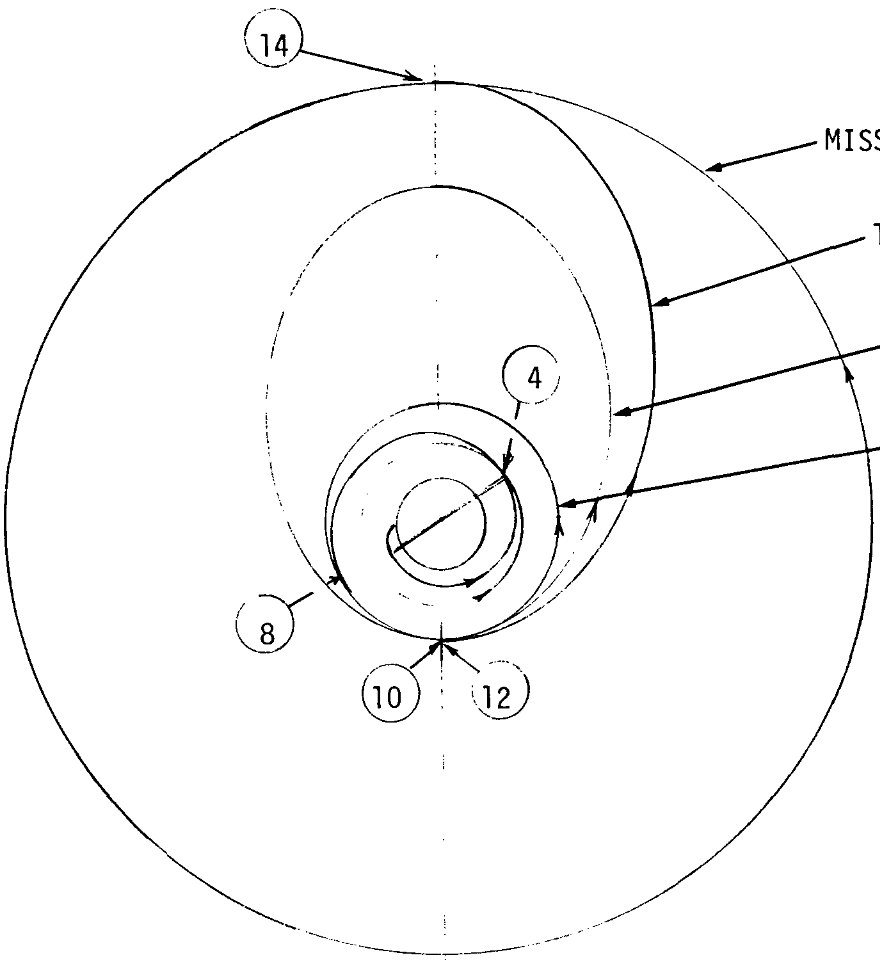
GEOSYNCHRONOUS TRANSFER ORBITS

Figure 4.1-1 illustrates the ascent mission profile, together with the times of major events. For this study, it has been assumed that upon orbit circularization at 160 n mi, the shuttle/tug/platform will complete 1-1/4 revolutions before insertion into the phasing orbit. It is also assumed that there will always be one phasing orbit before the platform is inserted into the geosynchronous transfer orbit.

A ground trace of an ascent profile is presented in Figure 4.1-2. This profile assumes a phasing orbit of nine hours, with insertion into the phasing orbit occurring from the first descending node. Geosynchronous orbit insertion occurs at a longitude of 100 degrees west. It is, of course, required that the geosynchronous orbit insertion point coincide with the location of the platform's mission. Various locations can be achieved by varying the phasing orbit period and/or effecting the transfer orbit insertion either at the descending or ascending node. In addition, the vehicle may remain in the 160-n mi parking orbit for insertion into the phasing orbit at later nodal crossings; i.e., second ascending or descending node, third, etc. Figure 4.1-3 presents phasing orbit duration versus destination longitude for transfer orbits from ascending and descending nodes.

It should be recalled that the first descending node opportunity occurs 1-1/4 orbits after insertion into the 160-n mi parking orbit, and the first ascending node opportunity occurs 1-3/4 orbits after insertion into the 160-n mi orbit.

The time to transfer from a 160-n mi orbit to synchronous orbit is 5.27 hours. The total delta-V required to transfer from a 160-nautical mile circular orbit to a geosynchronous orbit is equal to the sum of delta-V's for phasing orbit insertion, transfer orbit insertion, and geosynchronous orbit insertion, provided the phasing orbit apogee is less than geosynchronous orbit altitude. A delta-V penalty would be paid from selecting a phasing orbit that has an apogee greater than geosynchronous orbit altitude because the apogee must be lowered to achieve the final geosynchronous orbit conditions. For example, it can be determined from Figure 4.1-3 that if a geosynchronous insertion point of 165 degrees west longitude is desired, a phasing time of 13 hours would be required. The preferable way to meet this requirement is



SEQ.	Event	Time: Cum (hrs)	Time: Duration (hrs)	Lat.	Long.
1	Liftoff	0		28.5	80.55 W
2	Shuttle MECO	0.15		27.68	67.89 W
3	Coast to 100 nm		0.73		
4	Circularize at 100 nm			-27.68	100.93 E
5	Coast 1 revolution		1.47		
6	Transfer to 160 nm	2.35		-27.68	78.33 E
7	Coast to 160 nm		0.74		
8	Circularize at 160 nm	3.09		27.68	113.1 W
9	Coast 1-1/4 revolutions		1.83		
10	Phasing orbit insert	4.92		0	65.28 W
11	Phasing orbit coast		9.01		
12	Transfer orbit insert	13.93		0	159.22 E
13	Coast transfer orbit		5.28		
14	Geosync orbit insert	19.21		0	100.0 W

Figure 4.1-1. Geosynchronous Mission Ascent Profile

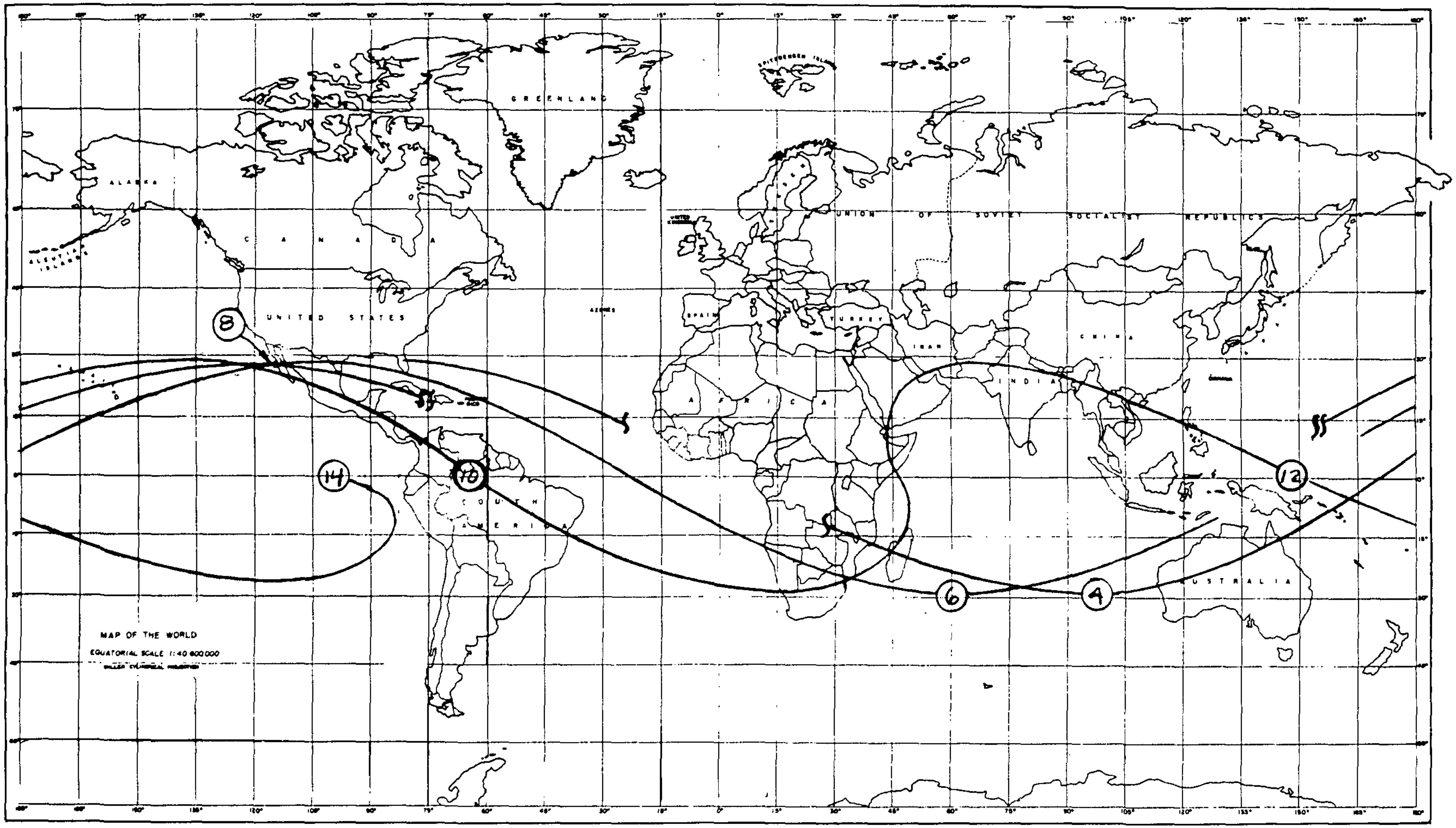


Figure 4.1-2. Geosync Ascent Ground Trace

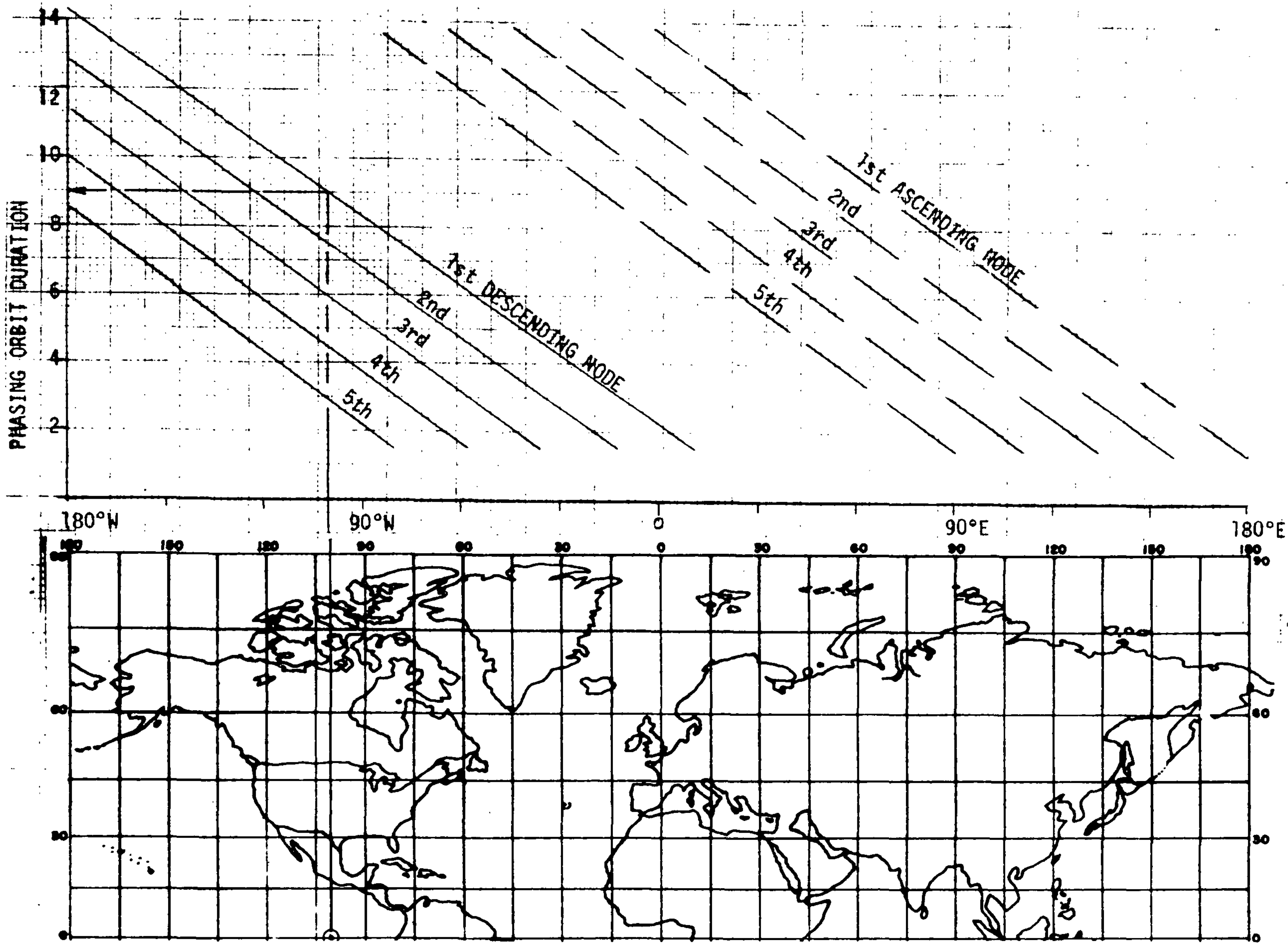


Figure 4.1-3. Phasing Orbit Duration

by means of two phasing orbits, each having a period of 6.5 hours. It should be noted that the 165 degrees west longitude position could also be achieved with a phasing orbit period of 11.5 hours from the second descending node.

With the phasing orbit period defined for a particular geographic location, it is next desirable to define the apogee altitude of the given phasing orbit.

Orbital period, τ, is defined as

$$\tau = \frac{2\pi}{\sqrt{\mu}} (a^{3/2}) \tag{4.1-1}$$

where

$$a = \frac{r_p - r_a}{2}$$

and r_a and r_p represent apogee and perigee radii, respectively. Solving the above for r_a,

$$r_a = 2 \left(\frac{\tau \sqrt{\mu}}{2\pi} \right)^{2/3} - r_p \tag{4.1-2}$$

Now with r_a defined, it is possible to solve for the impulsive velocity increment $\Delta\overline{V}_p$ at perigee required to achieve a phasing orbit with apogee radius of r_a. From Equation (3.3-2) of Volume III of this study.

$$\Delta\vec{V}_p = (V_{cp}{}^2 + V_p{}^2 - 2V_{cp} V_p \cos \varepsilon_p)^{1/2} \tag{4.1-3}$$

where
- V_{cp} = the circular orbit speed at the initial circular orbit altitude
- V_p = the speed at perigee of the transfer orbit
- ε_p = the magnitude of the simultaneous plane change performed at perigee of the transfer orbit

From Equation (3.3-6) of Volume III

$$V_p = V_{cp} \sqrt{\frac{2}{1 + r_p/r_a}} \qquad (4.1\text{-}4)$$

For an orbit of altitude 160 nautical miles

$$V_{cp} = 25{,}354 \text{ ft/sec} \qquad (4.1\text{-}5)$$

$$r_p = 21{,}897{,}904 \text{ ft} \qquad (4.1\text{-}6)$$

Using the value of $\varepsilon = 2.2°$ and substituting equations (4.1-4) through (4.1-6) into (4.1-3) results in

$$\Delta\overline{V}_p = 25{,}354 \left[1 + \frac{2}{1 + \frac{21{,}897{,}904}{r_a}} - 2\sqrt{\frac{2}{1 + \frac{21{,}897{,}904}{r_p}}} \right]^{1/2} \qquad (4.1\text{-}7)$$

Equation (4.1-7) expresses the total incremental velocity required to achieve an orbit having an apogee of r_a and a perigee of 160 nautical miles. If r_p represents the geosynchronous orbit altitude of 19,323 nautical miles, then

$$\Delta\overline{V}_p = 8{,}041 \text{ ft/sec}$$

Thus, if a phasing orbit is chosen that has an apogee of 19,323 n mi, the $\Delta\overline{V}_p$ required for geosynchronous orbit transfer is zero since the phasing orbit apogee is at geosynchronous altitude.

Equations (4.1-2) and 4.1-7), together with the geosynchronous orbit insertion location parametric data, are combined on a nomograph in Figure 4.1-4. In the subsequent timeline analysis, a geosynchronous platform over the U.S. at 100 degrees west longitude will be used as the reference mission. For this case, it may be determined from Figure 4.1-4 that the phasing orbit period is 9.01 hours with an apogee altitude of 16,700 nautical miles. The incremental velocity required for insertion into the phasing orbit is 7670 ft/sec, and the additional velocity required for insertion into the geosynchronous transfer orbit is 370 ft/sec.

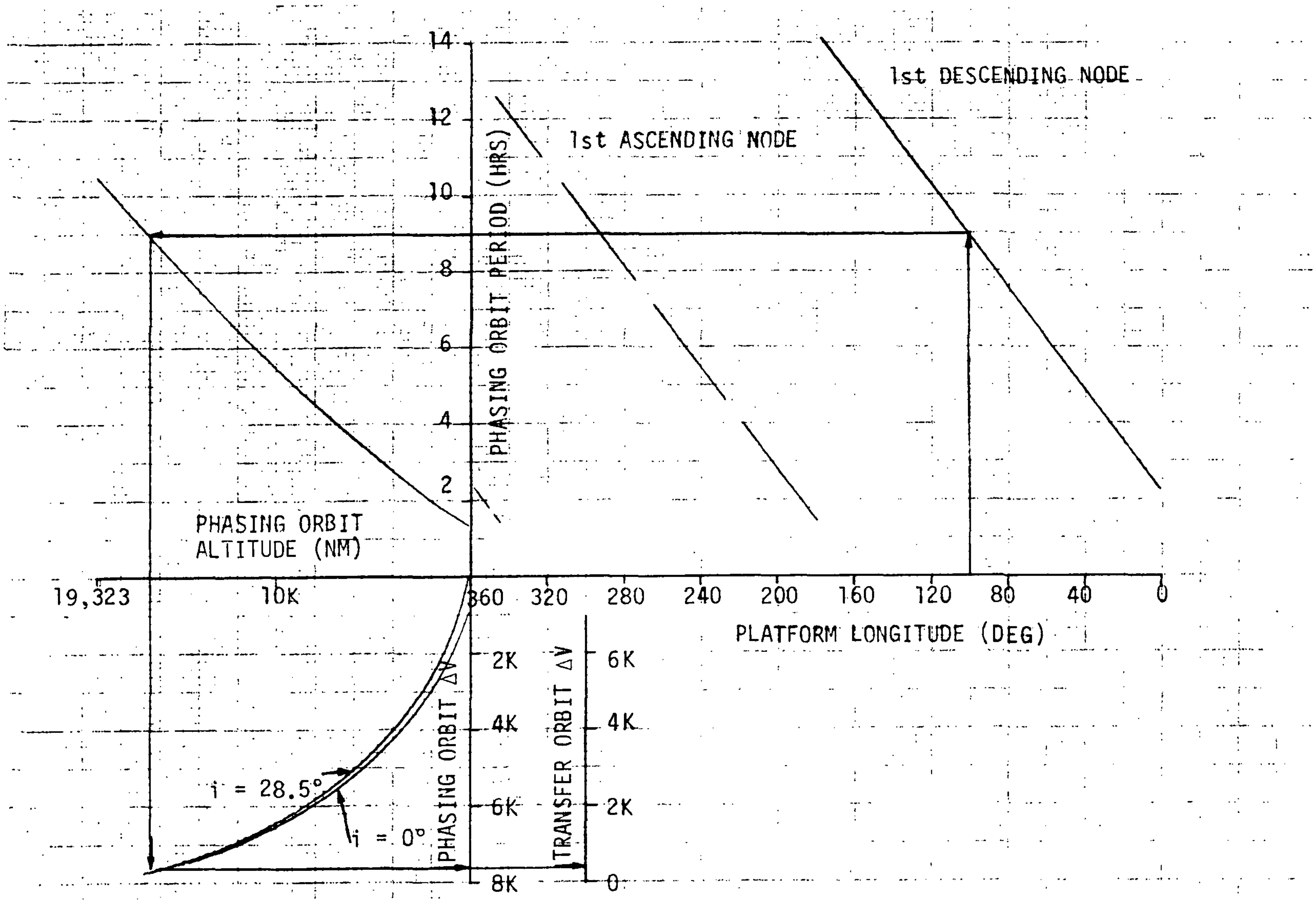


Figure 4.1-4. Geosync Mission Nomograph

GEOSYNCHRONOUS PLACEMENT AND SERVICING TIMELINES

The timelines for geosynchronous-orbit payload delivery and servicing are presented in two parts: (1) the complete mission timelines and events for all five modes (Figures 4.1-5 and 4.1-6), and (2) a more detailed definition of key operations involved in the mission timelines (Figures 4.1-7 through 4.1-12).

Table 4.1-1 provides a brief summary of the five modes and the configurations examined in this study.

Table 4.1-1. Mission Modes Definition

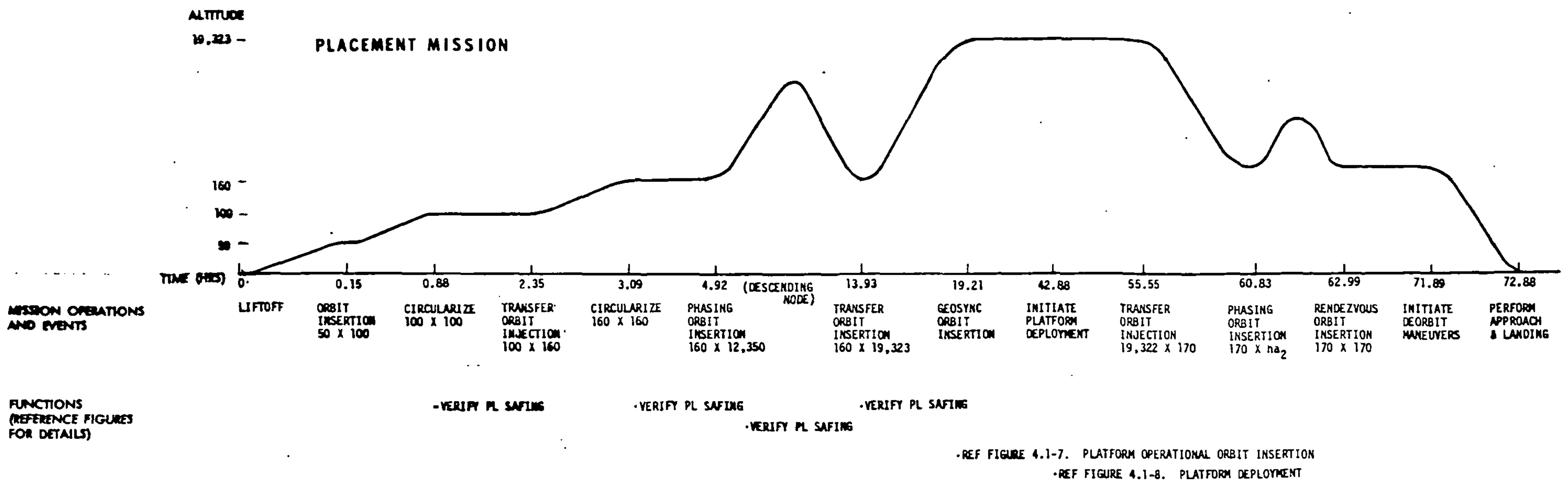
Mode	Configuration	Mission (hours)	Ref. Figure
Placement (unmanned)	Tug/platform	72.88	4.1-5
Servicing (unmanned)	Tug/RSU*	147.68	4.1-5
Placement/unmanned servicing	Tug/RSU/platform	140.09	4.1-6
Manned servicing	Tug/tug/CM**	143.66	4.1-6
Placement/manned servicing	Tug/tug/CM/platform	143.15	4.1-6

* Remote Servicing Unit
** Crew Module

Each of the timelines presented in Figures 4.1-5 and 4.1-6 schematically presents the mission profile, defines specific mission times for the major operations and events, and references other lower-level timelines that pertain to the mission mode being presented.

The first mission mode involved the placement in orbit of a single platform. Total time to arrival at geosynchronous orbit altitude is 19.21 hours. Once in orbit, it is necessary for the orbit transfer system (tug) to determine the present orbit parameters of the tug/platform and determine the necessary corrections required to achieve the final desired platform orbit. Because the baseline tug utilizes an autonomous G&N system, 23 hours are allotted in the mission to accomplish this function. Should ground-based tracking be utilized for navigation updating, the amount of time required for final insertion in the desired platform orbit can be reduced to approximately three to six hours. Also, the descent sequence requires a period of time (up to one shuttle orbit) for proper phasing with the earth orbiting shuttle.

There are two timelines referenced from the placement mission (Figures 4.1-7 and 4.1-8). Figure 4.1-7 provides a detailed breakout of the next lower level functions involved in the performance of operational orbit insertion in preparation for platform orbital placement. There are nearly 19 hours of coast operations prior to final orbit insertion.



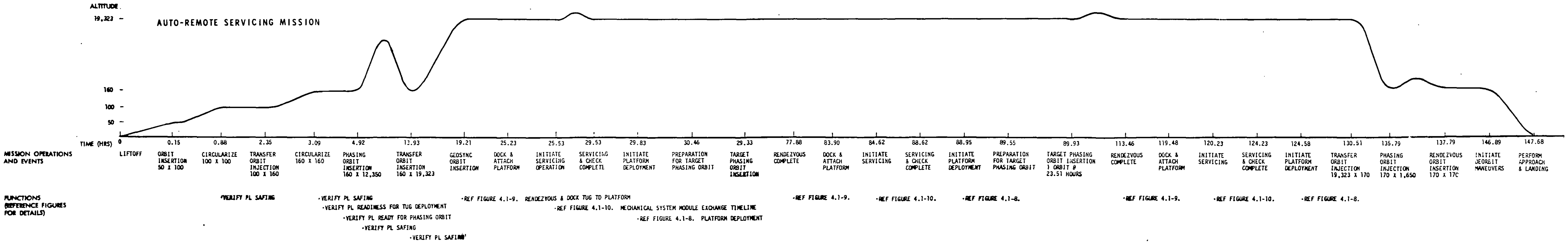
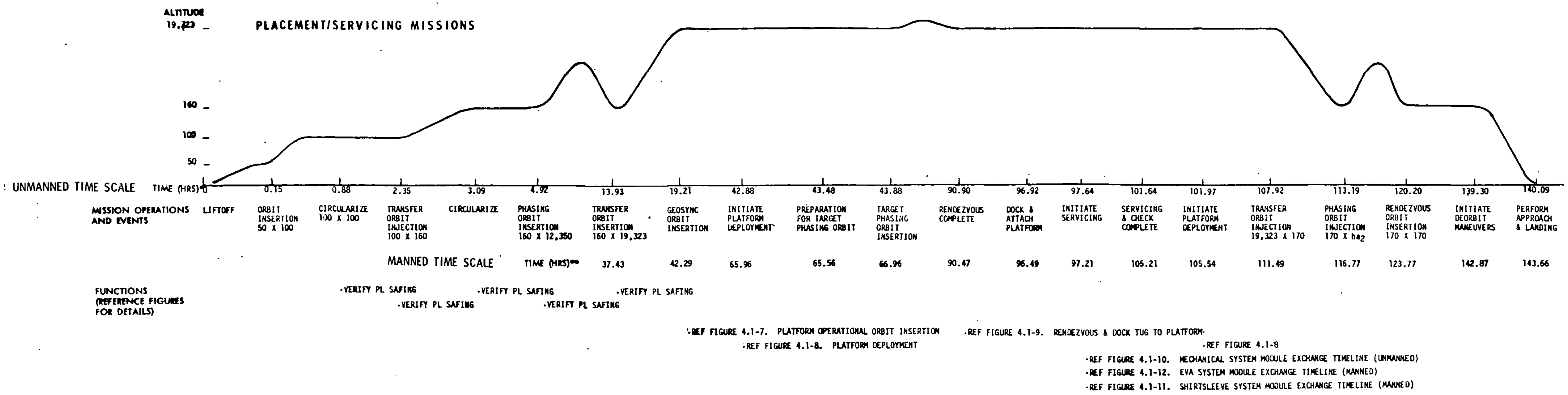


FIGURE 4.1-5. PLACEMENT MISSION AND AUTO-REMOTE SERVICING MISSION TIMELINES



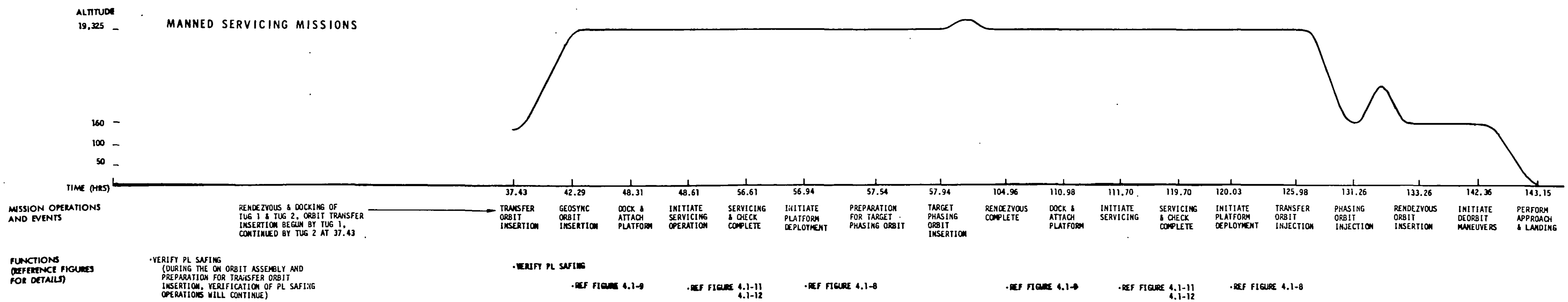


FIGURE 4.1-6. PLACEMENT/SERVICING MISSION TIMELINES

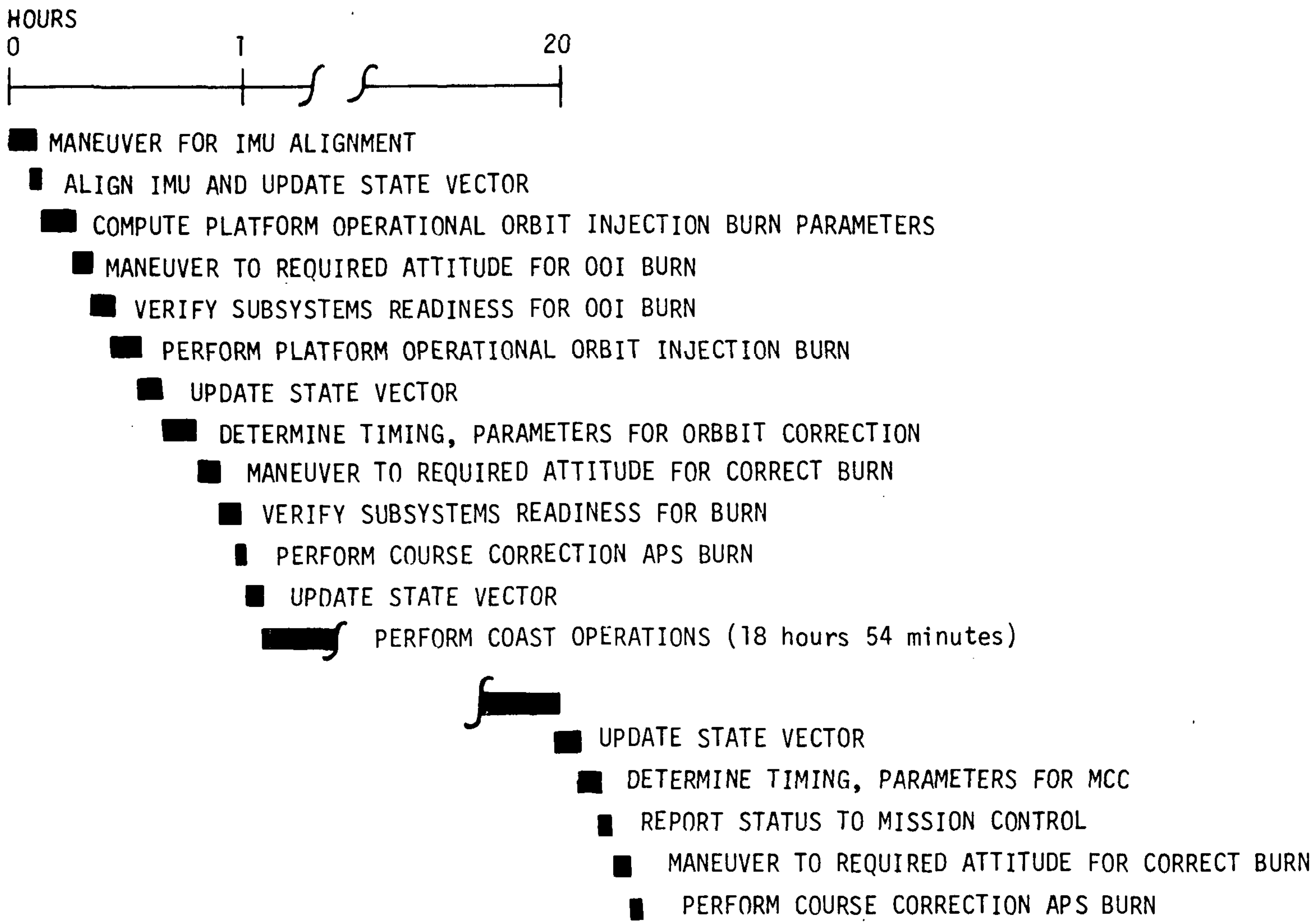


Figure 4.1-7. Platform Operational Orbit Insertion

Figure 4.1-8 defines the functions involved in the on-orbit deployment of a platform. One of the functions defined involves the establishment of ground communications prior to separation from the platform. The purpose of this function is twofold: (1) to allow the deployment and establishment of platform functions and (2) to check out and verify proper operation of the platform prior to separation. The underlying philosophy of the deployment operations is to perform as many platform operations as possible prior to physical separation of the platform from the transportation system.

If anomalies should be detected during checkout, several possible operations are possible:

1. To return the platform, if it is within the performance capability of the tug.

2. To place the platform in orbit in a standby or degraded operational mode so that it could be repaired on a subsequent mission.

3. To repair the platform prior to deployment.

The second timeline in Figure 4.1-5 is for an auto-remote servicing mission. The ascent profile for this mission is the same as for the placement mission. However, the post-orbit sequence differs considerably because the time required to achieve the final geosynchronous orbit parameters and to dock with the platform is much less than 23 hours. Although the orbital transportation system still assumes the use of an autonomous guidance and navigation system, a reduction in rendezvous and docking time is achieved because the tug is docking with an active vehicle (target). It is assumed that the platform target is equipped with a transponder and that although the initial on-orbit arrival errors are nearly the same for both servicing missions and placement missions, the final convergence of the errors can be achieved much more rapidly between the tug and the transponder-equipped platform. As a result of this more rapid convergence it is assumed that approximately five hours are required for final orbit refinement, rendezvous, and docking with the on-orbit platform. Figure 4.1-9 provides a detailed functional description of the operations leading up to the docking of the tug to the on-orbit platform.

After docking operations, the platform is ready for servicing operations. The timeline for auto-remote servicing given in Figure 4.1-10 is based upon servicing of three modular units, which is consistent with the 25-percent per year servicing levels considered in program evaluations (Volume VI of this study). Additional units could be serviced at an additional time of about 15 minutes each. After the servicing operation, the platform is reactivated, checked out, and deployed as defined in Figure 4.1-8.

The tug is employed for transfer to other platforms for servicing. The specific location of the platforms to be serviced will be defined prior to the mission to allow for proper sequencing of the servicing operations, allotment of required delta-V propellant, and conformance with the orbital lifetime of the tug. For the timeline in Figure 4.1-5, three space platforms were assumed to require servicing. Orbit transfer times of 48 and 24 hours were assumed based on two and one internal transfer orbits. Total mission time amounted to 147.68 hours or slightly more than six days.

0

- INHIBIT VENTING OF SYSTEMS (INCL RCS) THAT COULD CAUSE CONTAMINATION OF PLATFORM
- DEPLOY PLATFORM ANTENNAS, SOLAR ARRAYS
- ACTIVATE POWER, DATA MONITORING, ATTITUDE CONTROL, COMMUNICATION SYSTEMS
- ESTABLISH GROUND/PLATFORM COMMUNICATIONS LINK
- MANEUVER TO REQUIRED ATTITUDE FOR SEPARATION
- ACTIVATE PLATFORM EXPERIMENTS (AS REQUIRED)
- CHECK OUT AND ENSURE ALL PLATFORM SYSTEMS OPERATING SATISFACTORILY
- PERFORM STABILIZATION AND FINAL POINTING PRIOR TO SEPARATION
- VERIFY PLATFORM READY FOR DEPLOYMENT
- UNCOUPLE PLATFORM AND MANEUVER OTS TO SAFE DISTANCE
- STATIONKEEP WHILE PLATFORM UNDERGOES FINAL SYSTEMS ACTIVATION
- MONITOR FOR SATISFACTORY PLATFORM OPERATION
- REESTABLISH VENTING OF SYSTEMS (INCL RCS) THAT WERE INHIBITED FOR CONTAMINATION CONTROL

Figure 4.1-8. Platform Deployment Timeline

HOURS 0

MANEUVER FOR IMU ALIGNMENT, ALIGN, UPDATE STATE VECTOR

COMPUTE RENDEZVOUS ORBIT INJECTION BURN PARAMETERS

MANEUVER TO REQUIRED ATTITUDE FOR ROI BURN

VERIFY SUBSYSTEMS READINESS FOR ROI BURN

PERFORM ROI MAIN ENGINE BURN

UPDATE STATE VECTOR

PERFORM RENDEZVOUS ORBIT COAST OPERATIONS

ORIENT FOR ACQUISITION BY RENDEZVOUS RADAR

ACQUIRE AND LOCK ON TO PLATFORM

DETERMINE RENDEZVOUS MANEUVERS

MANEUVER TUG TO REQUIRED ATTITUDE FOR TPI BURN

VERIFY SUBSYSTEMS READINESS FOR TPI BURN

PERFORM TPI MAIN ENGINE BURN

COMPUTE COURSE CORRECT BURN PARAMETERS, COAST (4-1/2 hours)

PERFORM TPI MAIN ENGINE BURN

COMPUTE TERMINAL PHASE FINAL BURN PARAMETERS, COAST (4-1/2 hours)

MANEUVER TO REQUIRED ATTITUDE FOR INITIAL TPF BURN

PERFORM TPF MAIN ENGINE BURNS

TRANSLATE TO DOCKING LOCATION

MANEUVER TO DOCKING ATTITUDE

VERIFY PLATFORM READINESS FOR DOCKING

CLOSE AT CONTACT VELOCITY

DOCK AND ATTACH PLATFORM

DEACTIVATE PLATFORM SYSTEMS

Figure 4.1-9. Rendezvous & Dock Tug to Platform

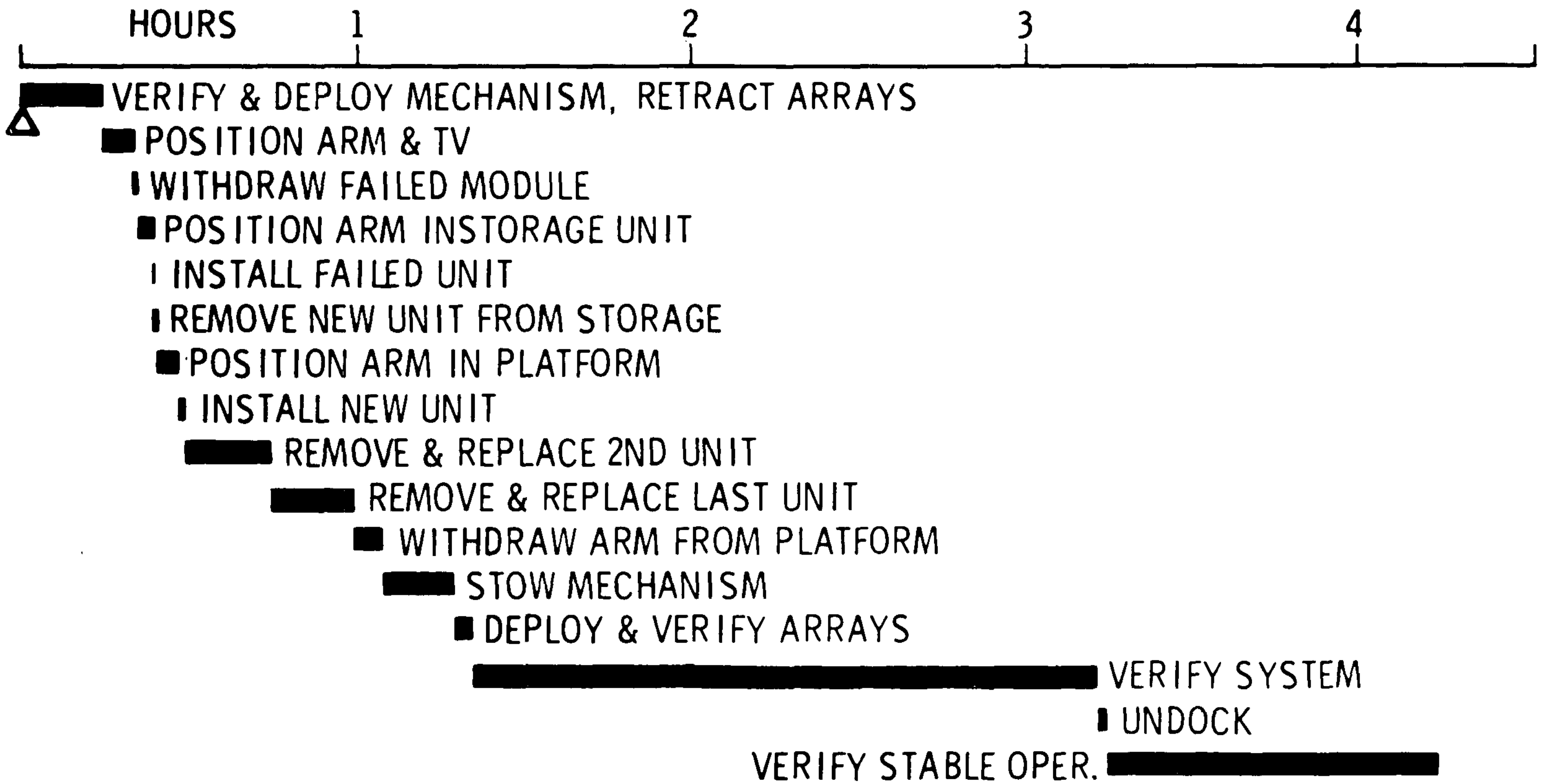


Figure 4.1-10. Mechanical System Module Exchange Timeline

The third mission mode for which a timeline was developed combines the two previously defined modes into a placement and auto-remote mission, presented in Figure 4.1-6. It may be noted that event times are also presented for the manned version of the placement/servicing mode, discussed in subsequent text. The first objective of the unmanned mission is to place the platform into geosynchronous orbit. As in the first mission mode, this mission is allotted 23 hours of orbit refinement at geosynchronous altitude prior to platform deployment. Once the platform is deployed, the tug performs an orbit transfer to rendezvous and dock to the platform to be serviced. The timeline for the unmanned placement/auto-remote mission involves the servicing of one platform and requires a total mission time of 140.09 hours.

Since the last two mission modes involved the use of a manned orbital transportation system, a two-shuttle, two-tug flight profile was required. In this profile, the lower stage (tug) supplies a part of the outbound delta-V, separates from the upper stage, and returns to the shuttle. The upper stage completes the intended mission and returns to the second shuttle orbiter for retrieval and return to earth.

The timelines for manned operations start at the point that the second tug is on the ascent transfer orbit after receiving an initial delta-V from the first tug. This time of transfer orbit insertion occurs at 37.43 hours. Figure 4.1-6 presents the timeline for the manned placement/servicing mission mode. The same basic mission event scheduling was followed as for the unmanned mission. In the actual servicing portion of the mission, there are eight hours for the servicing operations as opposed to four hours in the unmanned mission mode. The additional four hours are required for pressurization, crew ingress and egress, and other safety checks required for manned operation. It may be noted from the two timelines, Figure 4.1-11 for shirtsleeve servicing and Figure 4.1-12 for EVA servicing, that the actual time for module replacement is less than the time required in the unmanned configuration (Figure 4.1-10). The manned placement and servicing mission requires 143.66 hours for completion.

The last mission mode timeline (Figure 4.1-6, bottom) for manned servicing of two platforms covers a total time of 143.15 hours. Time increments for crew-related activities were the same as those in the manned placement/servicing mission above. However, differences in guidance operations between vernier trajectory adjustments for placement missions and the rendezvous sequence for servicing missions produce detailed timeline differences.

SUMMARY OF REQUIREMENTS

The previously developed timelines provide a basis for determining the key functional requirements resulting from the tug/platform interface. Concurrent with and in addition to these requirements, are certain continuous functional requirements not directly related to the mission timelines. Figure 4.1-13 provides an overview of the key functional requirements resulting from mission analysis. Further development of these requirements into a lower level of detail, together with appropriate trade analyses, is presented in Section 5.0 of this report.

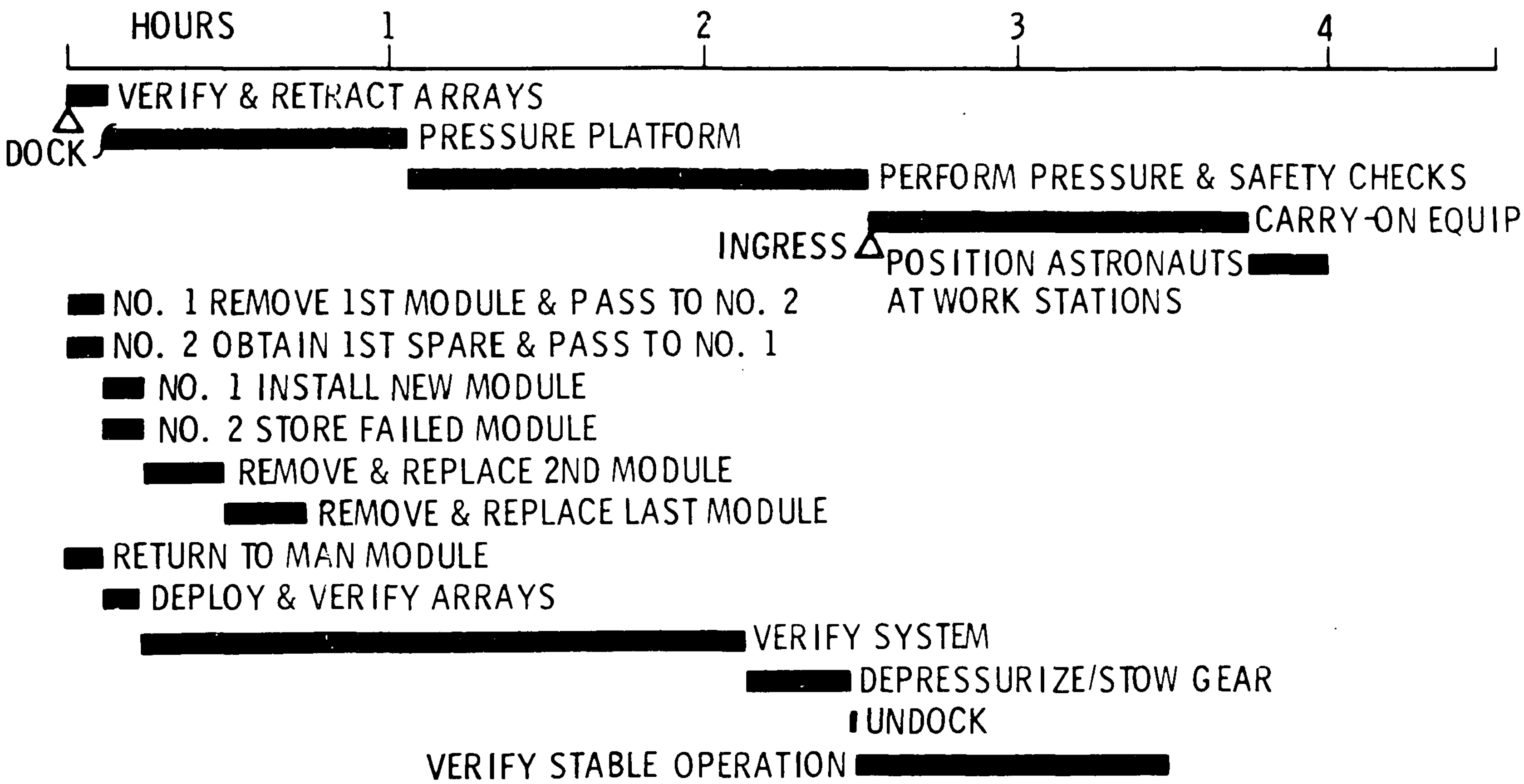


Figure 4.1-11. Shirtsleeve System Module Exchange Timeline

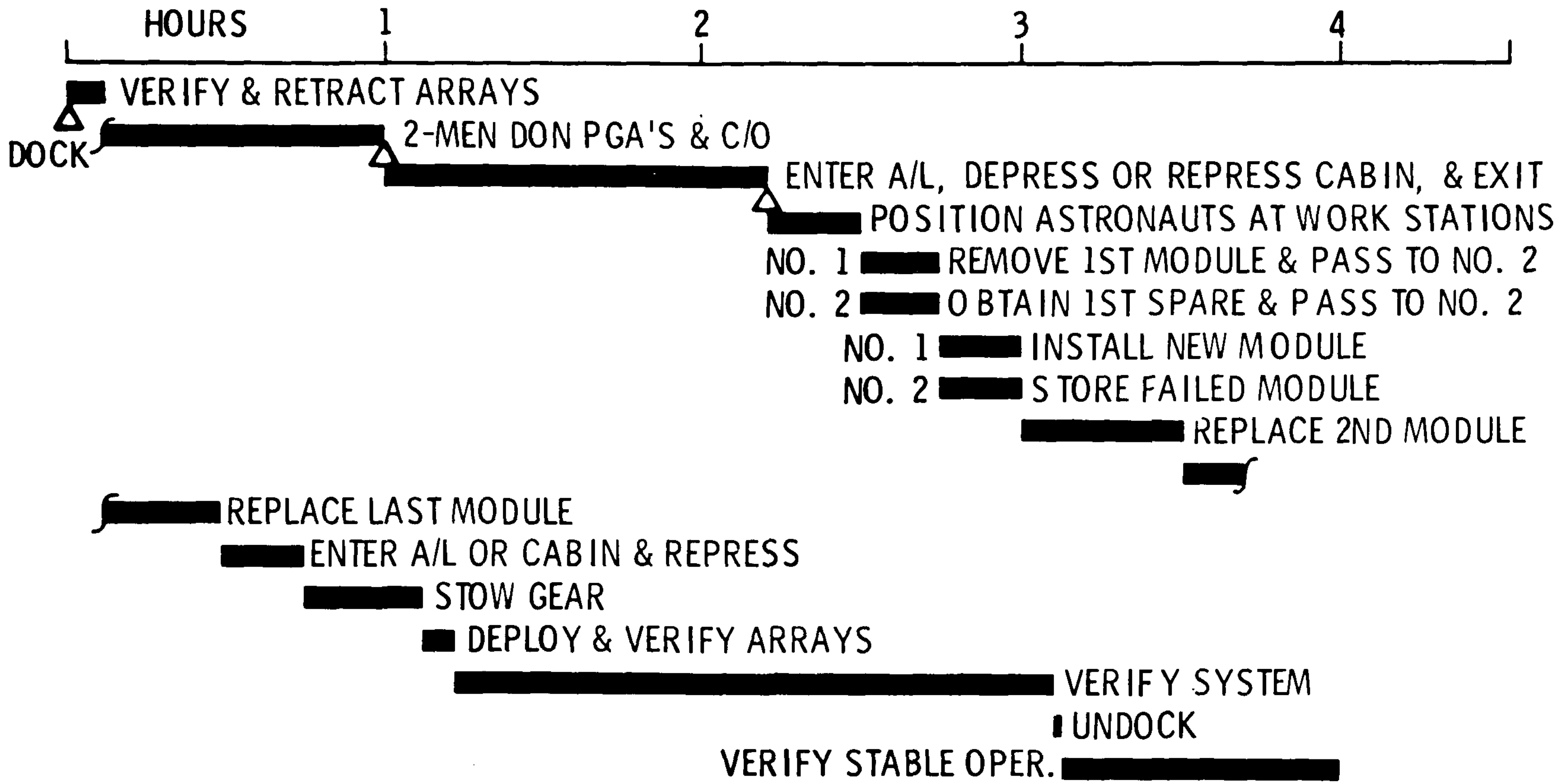


Figure 4.1-12. EVA System Module Exchange Timeline

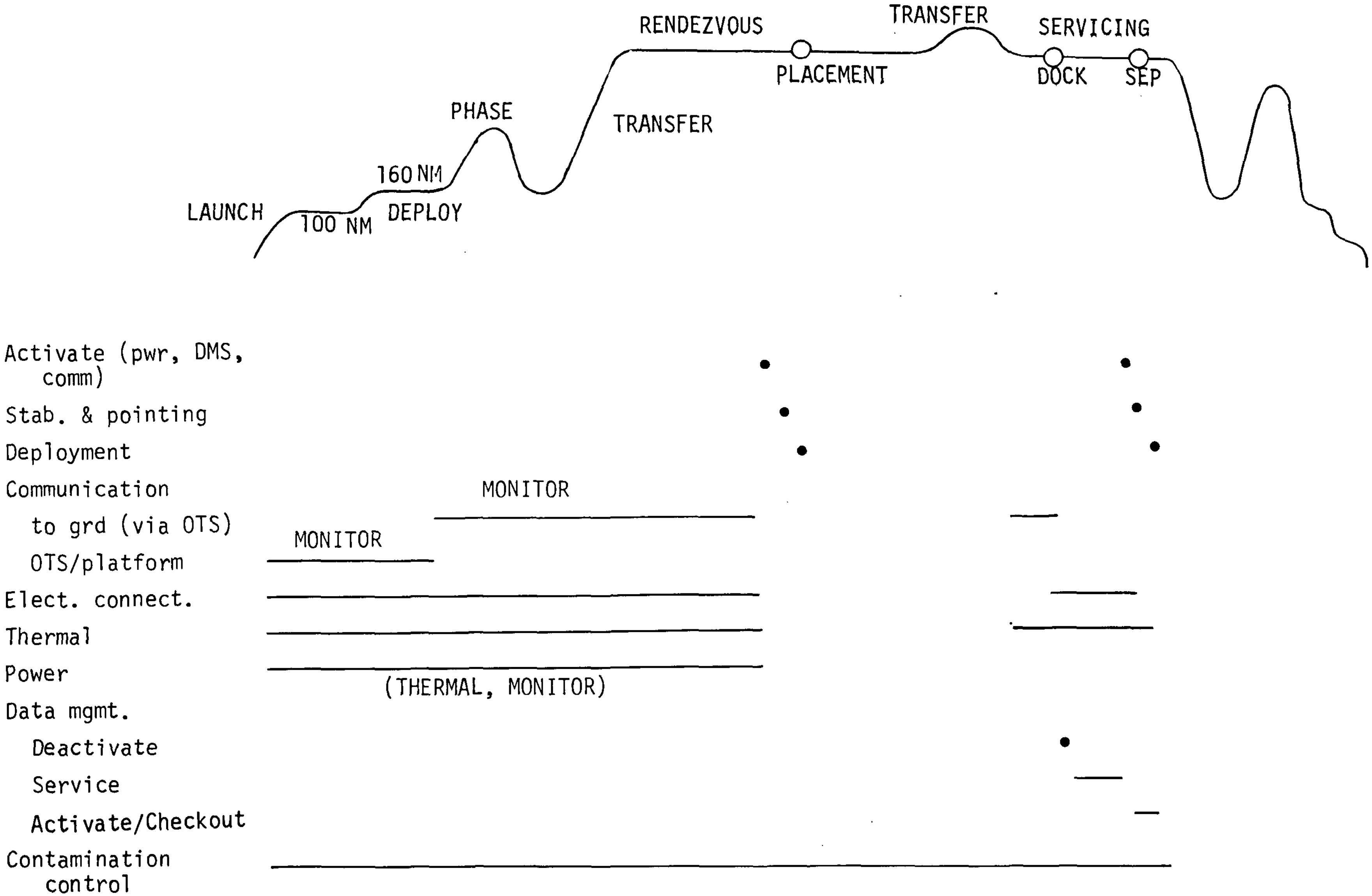


Figure 4.1-13. Tug/Platform Interface Identification
(Unmanned Placement & Servicing Mission)

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4.2 GEOSYNCHRONOUS PLATFORM - TRANSPORTATION SYSTEM INTERFACE IDENTIFICATION

The platform interface requirements were identified by analyzing the mission events in the timelines presented in Section 4.1. Three categories of interfaces were defined: physical, operational, and functional. Interfaces with both of the manned and unmanned tug configurations and the space shuttle were defined.

TUG-PLATFORM-INTERFACES

Both manned and unmanned tug configurations were evaluated to establish a composite platform-tug interface definition. The interfaces are summarized in matrix form in Table 4.2-1 for the various operational modes. Requirements common to more than one mode are identified with the number of the mode in which they first appeared.

Physical Interface

Physical interfaces encompass structural and mechanical interconnections between the tug configurations and the platform.

Docking and Separation. All missions require a method of separating and remating of the platform and the transport system. The interface mechanization must be standardized and interchangeable for the type of servicing mission planned. The auto-remote servicing mission requires docking with the platform support ring, which has a 12-foot OD and a 7-foot ID. In the servicing mode, post-docking operations require that the internal area of the toroidal rings of the platform be accessible for replacing supoort system and mission equipment modules.

The manned servicing mission requires an adapter to change the interface from the 7-foot diameter docking mechanism of the basic platform to a closed and pressurization interface that is compatible with the 5-foot diameter docking port of the manned tug. This adapter will not only permit the docking of the manned tug to the platform, but will also facilitate the direct ingress and egress of the crew to the habitable area of the platform to perform shirt-sleeve servicing of the basic platform operation.

Electrical Connector Mating and Demating. After docking and before separation from the platform, there is a requirement to mate and demate an electrical connector between the platform and the servicing unit. This electrical connector is standard on all platforms. Toroids are designed for either auto-remote or manned servicing. The method of mating the connector may differ between the auto-remote servicing and manned servicing modes because of the difference in the docking mechanism and the method of servicing (hinged versus fixed port servicing).

Table 4.2-1. Platform-To-Tug Interface Requirements Matrix

Interface \ Operational Mode	1. Placement	2. Auto-Remote Servicing	3. Placement/A-R Servicing	4. Manned Servicing	5. Placement/Manned Servicing
Physical Interfaces					
Docking and separation	Separation-placement	Revisit for servicing	Configurations 1 and 2	Configuration 2, shuttle compatible	Configurations 1 and 4
Electrical connector	Demateable auto-remote	Remateable auto-remote	Configurations 1 and 2	Remateable	Demateable-remateable
Operational Interfaces					
Deployment	Operational orbit placement	Post-servicing placement	Configurations 1 and 2	Configuration 2	Configurations 1 and 2
Stability and pointing by tug	Deployment, activation and checkout	Configuration 1	Configuration 1	Configuration 1	Configuration 1
Rendezvous	Not applicable	Tug/RSU with platform	Configuration 2	Configuration 2	Configuration 2
Predocking platform assessment	Not applicable	Platform configured and ready for docking operations	Configuration 2	Configuration 2	Configuration 2
Docking	Not applicable	Tug active - platform passive, auto-remote	Configuration 2	Manned docking	Configuration 4
Atmosphere control	Not applicable	Not applicable	Not applicable	Platform pressurization and circulation	Configuration 4
Post-docking servicing	Not applicable	Auto-remote from ground	Configuration 2	On-orbit manned	Configuration 4
Contamination	During transit and deployment	During servicing	Configurations 1 and 2	Configuration 2	Configurations 1 and 2
Functional Interfaces					
Power	Thermal control, activation, checkout and deployment	Platform power during servicing	Configurations 1 and 2	Platform power during servicing	Configurations 1 and 4
Communications with ground	Activation and checkout TV, data, control	Auto-remote servicing TV, data, control	Configurations 1 and 2	Ground assessment and control - data and control	Configuration 4
Data and control - hardwire	Activation and checkout to establish platform to ground control direct	Deactivation, activation, and checkout of serviced platform and establish platform to ground control direct	Configurations 1 and 2	Manned on-orbit or ground control of servicing operations	Configuration 4 and control of platform activation, checkout, and deployment

Operational Interfaces

Operational interfaces are those interface requirements derived from analyzing the operational effect of one vehicle upon another. They are:

1. Deployment of the platform in a placement mission or after servicing has been completed.

2. Stabilization and pointing of the platform by the tug during platform activation, servicing, and checkout prior to deployment.

3. Rendezvous with a platform on-orbit for the purpose of servicing.

4. The predocking assessment of the platform configuration and readiness for the subsequent docking and servicing operations.

5. The docking and safing operations.

6. The pressurization and circulation of the habitable atmosphere in the platform.

7. The potential contamination interface.

Deployment. After the platform has been delivered to its operational orbit or after it has been serviced, it must be accurately placed in its intended orbit. The forces imparted to the platform, such as accelerations and tipoff rates, should be minimized to preclude loss of communication and control of the platform. Adequate platform deployment parameters are:

Altitude:	$\pm$25 nm
Inclination:	$\pm$0.1 degree
Acceleration:	0.1 g
Tipoff Rate:	1 degree per second

Stabilization and Pointing. The platform control system remains quiescent until normal operations are initiated. The tug must provide the stabilization of the platform during the deployment of appendages, such as the solar arrays and antennas, and during the activation of the platform's stabilization subsystem. Because the platform is controlled from the ground via an RF communication link, this link must be established prior to deployment and separation by pointing the antenna at its ground station. These requirements are:

Stabilization:	0.1 degree per second
Pointing:	0.2 degree

Rendezvous. The tug has the capability to rendezvous to within 50 nautical miles of a geosynchronous platform either autonomously or with assistance from ground control. However, in order to accomplish terminal rendezvous maneuvers the platform must be compatible with the laser radar of the tug. The platform must include laser reflection.

Predocking Assessment. Prior to docking, it must be ascertained that the platform is properly oriented and stabilized. Appendages that cannot withstand the docking forces in their normal positions will have to be stowed or reoriented. As part of normal pre-mission planning, the serviceability of the platform will be determined by ground control via the RF-TT&C communication link.

Docking. The platform is required to be cooperative but passive (non-maneuvering) during terminal rendezvous and docking operations. Therefore, the platform must be stabilized to 0.2 degree per second and provide docking aids compatible with the tug docking concept. The attitude control system of the platform must be disabled immediately after docking.

Atmospheric Control. In a manned servicing mission, the platform must be pressurized with a habitable atmosphere, and adequate circulation provided between the habitable volume of the platform and the tug crew module.

Contamination Interface. Both manned and unmanned placement/servicing operational modes will develop potential contamination interfaces with platform. Leakage of gases, outgassing of materials, fuel cell purges, waste damage, and attitude control exhaust products are all potential sources of contamination. Various techniques are being evaluated in on-going tug and shuttle studies to minimize contamination problems. The unique aspects of on-orbit servicing of platforms must be examined to ascertain if any additional operational constraints are imposed upon the transportation system.

Functional Interfaces

Functional interfaces are those which support or supplement the platform subsystem to permit activation and deactivation of the platform, status monitoring, servicing, checkout, and like functions. These functional interfaces are: (1) power, (2) communication (RF and hardwire), and (3) data management.

Power. The platform's electrical power subsystem is designed for normal operations with solar arrays deployed and for utilizing chargeable batteries during solar occulted periods. Power is required for periods when the primary source of platform power is not available. These periods are during platform transit, activation, checkout prior to solar array deployment, and possibly during solar-array battery and/or power conditioner servicing.

Remote unit power is required for manipulator operation, TV and lights, data management, docking, and thermal control during transit.

Communication. During auto-remote placement or servicing of the platform, it is required that orbital operations be commanded, controlled, and visually assessed from the ground. This operation must be under the cognizance of the tug control center, because the tug provides the stabilization and control for the configuration. In most instances, the platform user's ground terminal will be a different ground terminal than the tug ground terminal.

In the manned servicing mode it is imperative that the operation be under the cognizance of the tug ground terminal. Maintenance of crew safety and crew module integrity will override any servicing operations. Although manned servicing operations will, in general, be accomplished autonomously, voice and data communication will be required with the ground to assist the crew in validating replaced platform subsystems and equipment.

In the placement or servicing of a platform, it is necessary to perform the functions of activation, checkout, deactivation, and fault isolation of all modular assemblies. Since the deactivation or replacement of the platform's communication, data management, or power subsystems would interrupt ground communication directly from the platform, a command/data transfer control interface between the platform and the tug is mandatory.

Data Management. The auto-remote and manned missions require the external processing of data received, the assessment of data, and the issuance of control commands to the platform in performing placement or servicing operations. The data processing requirements that would be imposed upon the tug configurations, especially if multiple platforms were involved on a single mission, would be prohibitive. Thus function must be provided by ground control.

SPACE SHUTTLE-PLATFORM INTERFACES

The potential interfaces between the space shuttle and platforms are significantly less in number and complexity when compared to tug platform interfaces.

Physical Interfaces

For four out of the five modes considered, the platforms are cantilevered off the forward end of the tug as depicted in Figure 4.2-1. This concept is the baseline approach for all tug payloads. The manned placement/servicing mode requires a structural interface between the shuttle and platform. In order to maximize shuttle payload efficiency the manned tug is delivered to orbit in one shuttle. The first stage tug and platform are delivered in the second shuttle. If the platform was cantilevered from the first stage tug in the shuttle bay a second docking port would be required on the platform to assemble it to the manned tug; the platform-manned tug would then be separated from the first stage tug, rotated 180 degrees, and then the two tug stages would be mated. The requirement for adapters between platforms and a first stage tug, which must encompass the folded up appendages (antennas, etc.), does not appear to be a practical approach. Therefore, the preferred approach is to separately attach the platform in the shuttle cargo bay. Figure 4.2-2 illustrates this concept.

Those configurations which have the tug payload (platform, RSV, crew module) cantilevered from the front end of the stage involve only the shuttle and tug stage during the deployment and separation operations. The entire shuttle payload is deployed from the shuttle cargo bay by a pivotal motion of the support ring at the aft end of the tug. The baseline tug stage occupies 35 feet of the 60-foot cargo bay, but only 290 inches are available for the

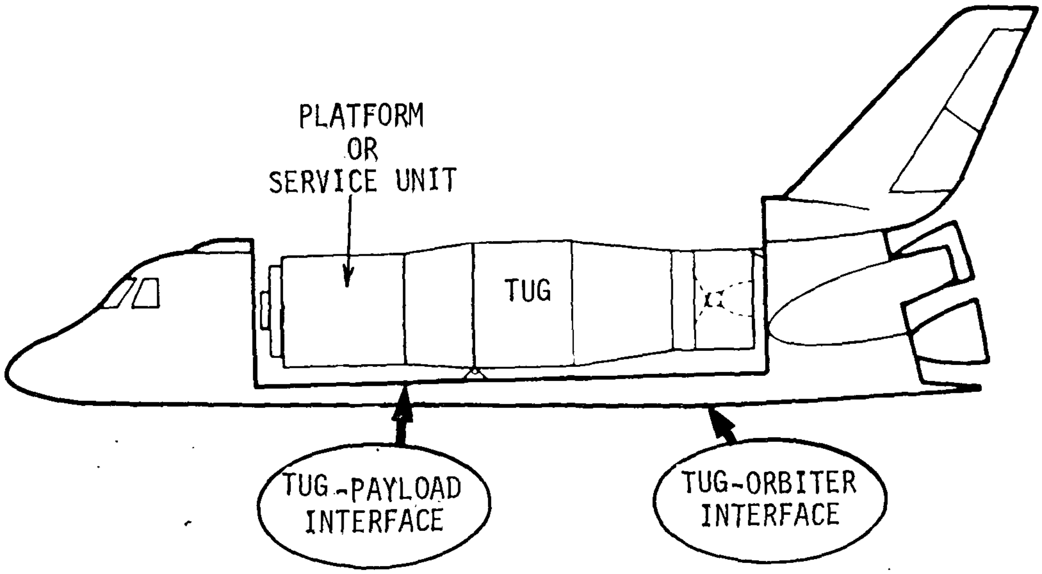

Figure 4.2-1. Platform/OTS to Orbiter Physical Interface

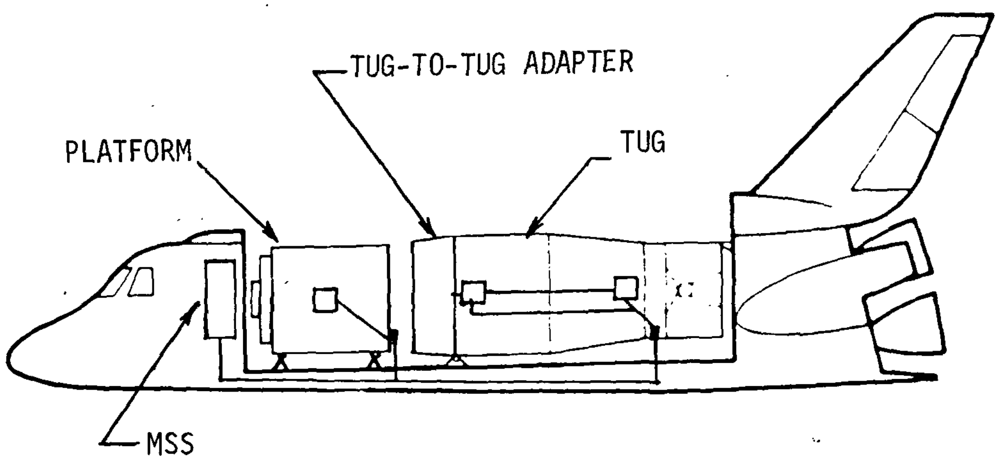

Figure 4.2-2. Shuttle Delivery of Separate Platform and Tug

tug payload (including tug payload adapters). The remaining ten inches are required for clearance during the pivoting of the tug-payload.

The one operational mode (manned placement/servicing) when the platform is directly mounted to the shuttle imposes the requirement on the platform to include both shuttle bay and manipulator attachment mechanisms. The mechanisms can be similar to those used for the tug.

Separate mounting of a platform in the shuttle also imposes a requirement for an electrical interconnect between the shuttle and the platform. This connection is required for safety monitoring and control as well as potential checkout operations.

Operational Interface

The only operational interface defined is that associated with the potential contamination problem. However, platforms do not present any unique operational constraints. Procedures developed for contamination control with other shuttle payloads will be equally applicable to platforms.

Rendezvous and docking operations do not directly involve the platform. The operations are conducted between the tug, shuttle, and ground control.

Functional Interfaces

The functional interfaces required between the platform and the shuttle are (1) power, (2) safety monitoring and control, and (3) potential activation and checkout.

Power. If the platform requires power during periods of prelaunch through tug activation, it must be provided by the orbiter, because the tug power system is not activated during these periods.

Safety Monitoring and Control. Platform support system and mission equipment that include assemblies that have a failure mode which could jeopardize the safety of shuttle operations must provide status data to the shuttle mission/paylod specialist station and the commander/pilot station. Provisions for overriding the platform control of these critical functions by the shuttle crew must also be provided.

Activation and Checkout. In the process of activation and deployment of the tug, the platform and/or servicing unit must be activated and checked out to the depth required to determine its readiness to respond to control from or through the tug, its operability on tug power, and its capability to perform the subsequent mission operations.

5.0 INTERFACE DESIGN TRADES

In this section,the platform-transportation system interfaces that were identified in Section 4.0 are analyzed to determine the preferred method of implementation.

The analyses are presented as a function of the three elements of the space transportation system. Section 5.1 pertains to the platform interfaces with the unmanned tug; Section 5.2, the manned tug; and Section 5.3, the space shuttle.

Although each interface is discussed, in those cases where the baseline design concept is adequate, only a description of the concept is presented. The trades conducted in the definition studies of the transportation system elements to select the concept are not repeated in this report.

Figure 5.0-1 depicts the location of the TT&C antenna, TV and laser radar passive docking aids, electrical umbilical, and docking interfaces of the platform. This baseline design concept is referred to throughout the ensuing text of this section (5.0).

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Figure 5.0-1

SCALE 1/30	DR. / DATE / CHECK	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA
COMMON SUPPORT MODULE SYNCHRONOUS ORBIT PLATFORM SERVICING STUDY		2339-19A

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5.1 UNMANNED TUG INTERFACE CAPABILITY VERSUS PLATFORM REQUIREMENTS

A comparison was made of the capability of the baseline unmanned tug to accommodate the interface requirements of platform auto-remote servicing and placement modes of operation. Table 5.1-1 summarizes the results of the comparison. The following narrative expands upon the adequacy or inadequacy of the tug to satisfy the interface requirements. If the interface requirement is not met by the baseline concept, the alternatives and options are discussed and a recommendation or selection of the interface implementation method is made.

Figure 5.1-1 depicts the auto-remote servicing concept and physical interfacing relationship between the tug and the platform. It is referred to throughout the text.

DOCKING AND SEPARATION STRUCTURE

The configurational or structural interface requirements are not met by the baseline tug utilizing the probe and drogue for docking and separation operations. The primary reason for the incompatibility is the platform requirement for inside servicing; the selection of the toroidal ring for access would require the removal of the probe and drogue after docking, and its replacement after servicing. The ring frame docking and separation mechanism of the platform was selected because it permits maximum access into the interior of the platform with a minimum of adapter length and weight, and because no assembly/disassembly operation is required. Also, the ring frame concept is more compatible than a probe and drogue concept with large payloads, from a stress standpoint. The access requirement also requires that the interface be hinged to permit the platform to be serviced by the manipulator located on the servicing unit, as depicted in Figure 5.1-1.

ELECTRICAL CONNECTOR

The baseline tug includes an electrical connector interface with its payload, but the design concept does not include provisions for on-orbit remating of the connector. Neither on-orbit servicing nor payload retrieval were considered in the concept selection. In the case of geosynchronous platforms, the tug-platform connector interface must be accomplished several times during the mission life of the platform.

The major difficulty in accomplishing the interface is the standardization of the connector, including assignment of functions to specific pins. If only one platform were delivered, retrieved, or serviced per mission, standardization would not be required; an unique adapter that will mate with the platform involved on given mission could be installed on the tug prior to mission initiation. But in this study it has been established that as many as four platforms could be involved on a single mission (unmanned tug placement/auto-remote servicing mode).

Table 5.1-1. Unmanned Tug Interface Capability Versus Platform Requirements

Interface	Unmanned tug capability	Platform/servicing unit requirements
Docking/separation structure	Probe and drogue	7' ID ring frame
Electrical connector	On-orbit separation only	Multiple mate and demate operations
Deployment	±25 n.mi. alt, 0.1° incl., 0.1 g accel., 1°/sec T-0 rate	Adequate
Stability and pointing	0.1°/sec, 0.2°	Adequate
Rendezvous - within 50 n.mi.	Autonomous or ground track	Adequate
Terminal rendezvous	Laser radar	Adequate - passive aids
Predocking assessment	Remote TV	Adequate
Docking	Laser or TV	Adequate - passive aids
Post-docking servicing	None	Power, data, control ground communications
Power to payload	700 watts - 40.0 kw hr	550 watts - 50 kw hr

Figure 5.1-1

SCALE 1/20	DR. / DATE / MODEL	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA
ON-ORBIT SERVICING SYSTEM SYNCHRONOUS ORBIT PLATFORM SERVICING STUDY		2339-21A

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It is unrealistic to assume that complete standardization of the connectors for all of the platforms placed in operation over a ten-year period can be achieved. Alternate approaches include adapters, multiple connector locations, and a large complement of spare pins in a standardized connector configuration.

If adapters are used, then as many as three changeouts could be required on a placement/multiplatform servicing mission. Either the manipulator would be required to make adapter interchanges or as each adapter is used it would be automatically jettisoned.

Multiple connector locations on the tug could accommodate several platform configurations, but the tug wiring harness would become very complex. Also, in order to maintain adequate clearance for auto-remote servicing, the connector must be located in the "hinged" area of the platform as shown in Figure 5.1-1.

Standardization of a basic connector configuration does not appear to be an insurmountable problem. Specific pin assignments,and thus a complete list of electrical interface connections for such a long-term program, are the primary concerns. Power, data transfer, and command links are the proposed tug-platform electrical interconnections. Even with redundancy provisions, less than 20 pins would be required to accomplish the interface. Umbilicals of 40 and more pins, which could be adapted for on-orbit mate-demate operations, are currently in use. Thus, greater than 100-percent growth or reassignment of electrical interconnects could be provided with current technology.

Because of the complexity of the operations associated with the on-orbit changeout of electrical adapters, and the operational and structural constraints associated with multiple connectors, the "oversized" connector is the preferred approach.

DEPLOYMENT

In establishing the deployment capability of the baseline tug, the alternates were: (1) the tug inject the payload into the final accurate orbit or (2) the tug provide a nominal placement and the payload provide the final orbit trim. Since some of the tug payloads (other than platforms) require autonomous placement operations and short reaction times,the second approach was selected. Within the constraints of current technology only long periods (days) of iteration of ground tracking data will permit precise geosynchronous orbit placement. The nominal emplacement accuracy of the tug is ±25 nm and 0.1-degree inclination. The propellant sizing of the platforms synthesized in this study included allowances for final orbit trim from these values.

The imparted acceleration and/or tipoff rate is inherently a part of the separation problem. Where soft separation is required due to appendages being deployed, the design should withstand an imparted acceleration of 0.1 g. Where this is not a factor, a tipoff rate of one degree per second maximum should not be detrimental to platform operations.

STABILITY AND POINTING

The requirements for independent platform operation range from 0.1 degree/second and 0.2 degree to 1 arc second/second and 10 arc seconds stability and pointing, respectively. However, the interface requirement is for the tug to provide adequate stability for servicing operations while docked to the platform and to point the platform TT&C antenna at its ground station to provide uninterrupted communications throughout attached operations. The tug is not required to duplicate the independent platform capabilities. The tug capability of 0.1 degree/second stability and 0.2 degree pointing are adequate for placement and servicing operations.

RENDEZVOUS

The rendezvous operation is divided into two phases: (1) rendezvous to within acquisition range of the platform, and (2) terminal rendezvous, where the tug must position itself (relative attitude and alignment) to prepare for final docking with the platform.

Rendezvous to Within 50 Nautical Miles

There are two methods available to the tug to rendezvous to within 50 nm of the platform. First, the tug possesses the capability to autonomously rendezvous with a known point in geosynchronous orbit to within ±25 nm and 0.1 degree inclination. Second, ground control can track the tug and the on-orbit element, perform ranging calculations, and update the required maneuvers and delta-V commands to the tug. Both methods are adequate and do not impact the platform configuration.

Terminal Rendezvous

When the tug is within 50 nm of the desired platform, it is within its laser radar acquisition range. The platform is passive but attitude stabilized during terminal rendezvous maneuvers. It contains passive corner cube optical reflectors to enable the tug to determine relative attitude orientation and alignment. Spherical coverage is required. In theory, eight-corner cubes would provide spherical coverage. However, platforms with such appendages as antennas and solar arrays that could occult these reflectors would require additional reflectors. A typical requirement might be 12-corner cube reflectors.

PREDOCKING ASSESSMENT

The initial assessment of the readiness and capability to dock with a platform and service it is based upon the telemetry data from the platform to ground. Final predocking assessment can be adequately accomplished by the use of the TV included in the baseline tug. The platform external configuration, physical status of appendages, and dynamic control actions can be adequately evaluated by remote TV from the tug.

DOCKING

The tug provides the capability to perform the docking operation by either of two methods, both of which are adequate and acceptable for the platform. The docking maneuvers and operations are normally performed by ground control utilizing television data. A passive alignment target (standoff cross) is required (see Figures 5.0-1 and 5.1-1) on the platform to provide precise alignment cues and closing rate to the remote television pilot. The other method available is to use the tug terminal rendezvous radar. Corner-cube reflectors are required on the platform docking interface opposite the laser radar to provide for sensing the relative attitude, range, and angle data required to perform the docking operation.

POST-DOCKING SERVICING

Auto-remote servicing of platforms imposes unique requirements on the tug. A remote servicing unit (Figure 5.1-1), which includes replaceable module storage, a manipulator for module interchange, and a manipulator for lights and TV was synthesized. The RSU requires not only power but telemetry, TV, and command/control interfaces with both the platform and ground control. It is impractical to assume that any of these functions can be provided by the platform because the platform servicing activity could involve one of the modules required for RSU data relay.

Three approaches for providing the relay of data during the servicing operation were evaluated. They are:

1. Incorporation of dedicated equipment in the RSU
2. Utilization of the tug communication subsystem
3. Utilization of the tug communications and data management subsystem

Figure 5.1-2 depicts the first approach, independent RSU equipment. During servicing operations the tug and the RSU data relay links with ground control would be operated simultaneously, since the tug provides the attitude stabilization and control function. This approach does not require a hardware interface between the tug and the RSU. However, the duplication of equipment is questionable. Both the tug and the RSU require a full complement of communications and data processing equipment.

The second approach, which is illustrated in Figure 5.1-3,utilizes the tug communications subsystem to provide the RF link for the auto-remote servicing operation. This option utilizes the docking TV link of the baseline tug for the servicing operation by coax switching of the docking TV and the manipulator TV to the tug transmitter. An independent RSU telemetry link is provided by adding a subcarrier modulator PCM data link to the tug RF multiplexer. Data rates up to 25 Kbps are readily accommodated by present state-of-the-art subcarriers. The tug 2 Kbps command uplink is used for both tug and RSU control by inter-leaving coded digital commands on a single RF carrier. This approach requires minor modifications of the tug communications equipment, and some additional

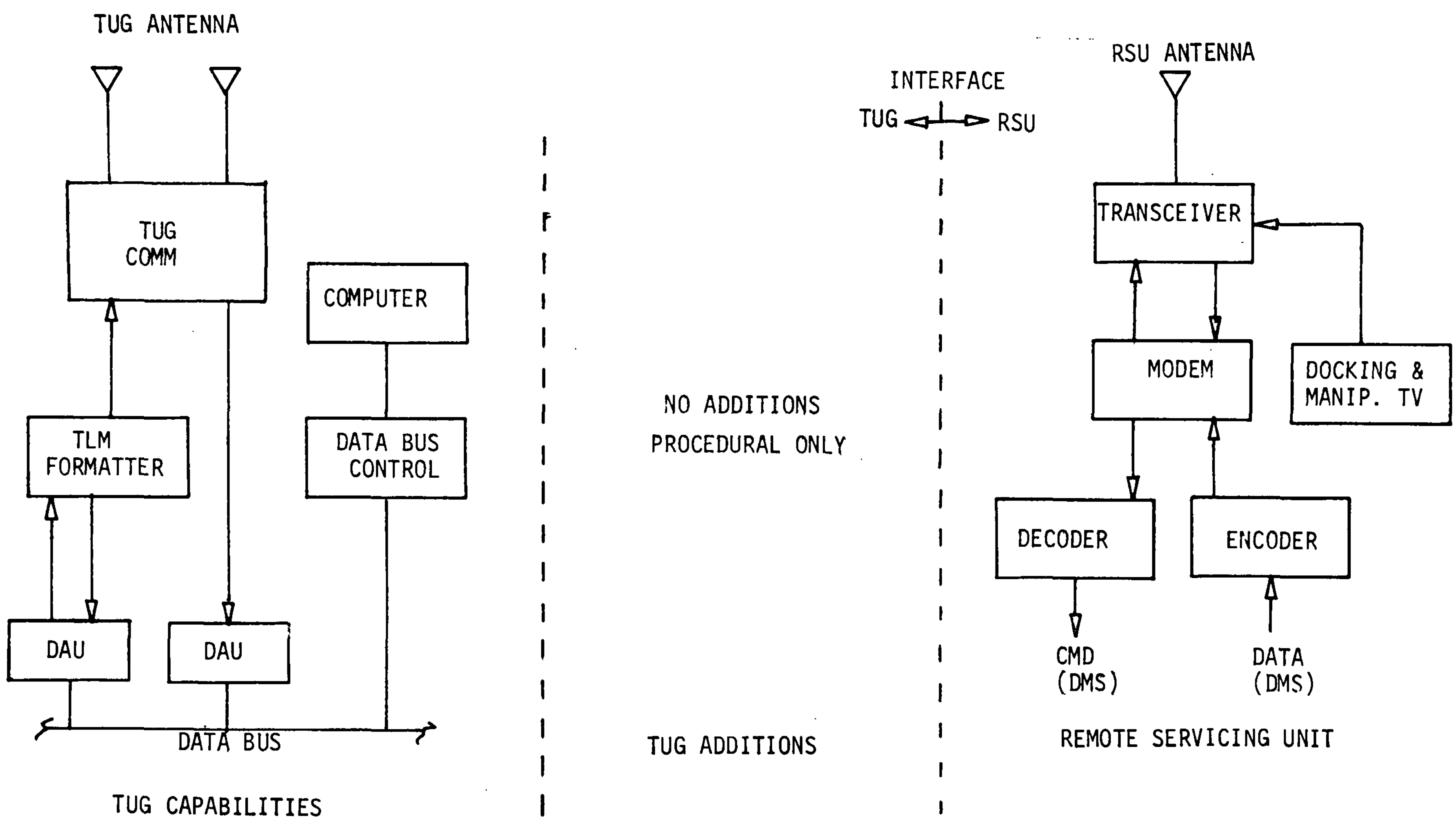
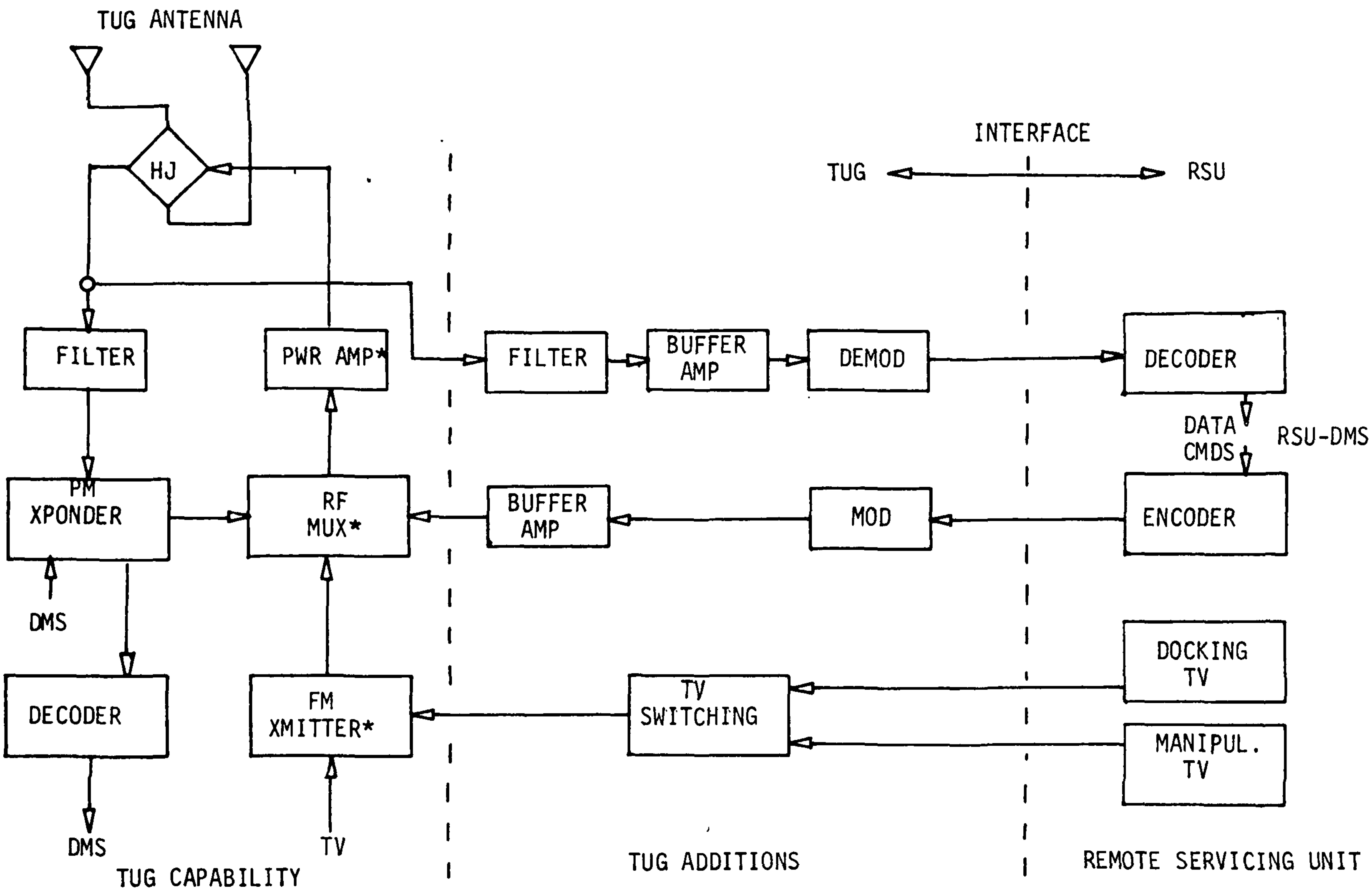


Figure 5.1-2. Direct Data Relay Link to Servicing Unit



*TUG MODIFICATIONS

Figure 5.1-3. Data Relay through Tug Communication Subsystem

equipment must be included in the tug to simply the interfaces and operations of RF equipment.

The third approach (Figure 5.1-4) provides the data relay link to ground control for the auto-remote servicing operation through the tug communication and data management subsystems. This approach minimizes the equipment of the combined tug and RSU but requires major modification to tug subsystems. The modifications are particularly evident in the software and data management subsystem of the tug. These modifications also significantly increase the complexity of software integration and simulation during mission planning activities.

Table 5.1-2 presents a comparison of the data relay requirements for the servicing operation and the capability of the baseline tug. In all cases the tug capability equals or exceeds the requirements of the servicing operation if proper interfacing of the data is provided.

Table 5.1-3 summarizes the evaluation of the three approaches. Although option 1 is the approach with the least impact on the tug, option 2 (utilization of the tug communications equipment) is preferred. This approach does not impact tug software and data management equipment and neither does it require the duplication of communications equipment. The required modifications to the tug are considered to be minor. The required additional equipment could be developed in kit form and installed only on auto-remote servicing missions of the tug.

POWER

Both the platform and the RSU require power during placement and servicing missions. Thermal control and checkout/monitor functions of the platform establish its demands. Operation of the manipulator, TV, lights, and data processing equipment in the RSU set its requirements. Power/energy timelines that correspond to the mission profiles developed in Section 4.1 for the three unmanned operational modes were constructed to determine the total tug payload electrical requirements.

The requirements for the platform and the RSU during transit, activation, and servicing are delineated in Table 5.1-4. The power and energy requirements of the tug for each mission are also indicated in the table. Based upon the tug capability to provide 1500 watts of power and 140 kilowatt-hours (kwhrs) of energy the data indicate that the tug can support either the platform placement mission or a three-platform servicing mission; the baseline tug cannot support a combination of the two missions. An additional 12 kwhrs of electrical energy is required.

Three approaches were evaluated:

1. Increase the fuel cell reactants of the tug

2. Install batteries on the RSU

3. Utilize the power source of the platform

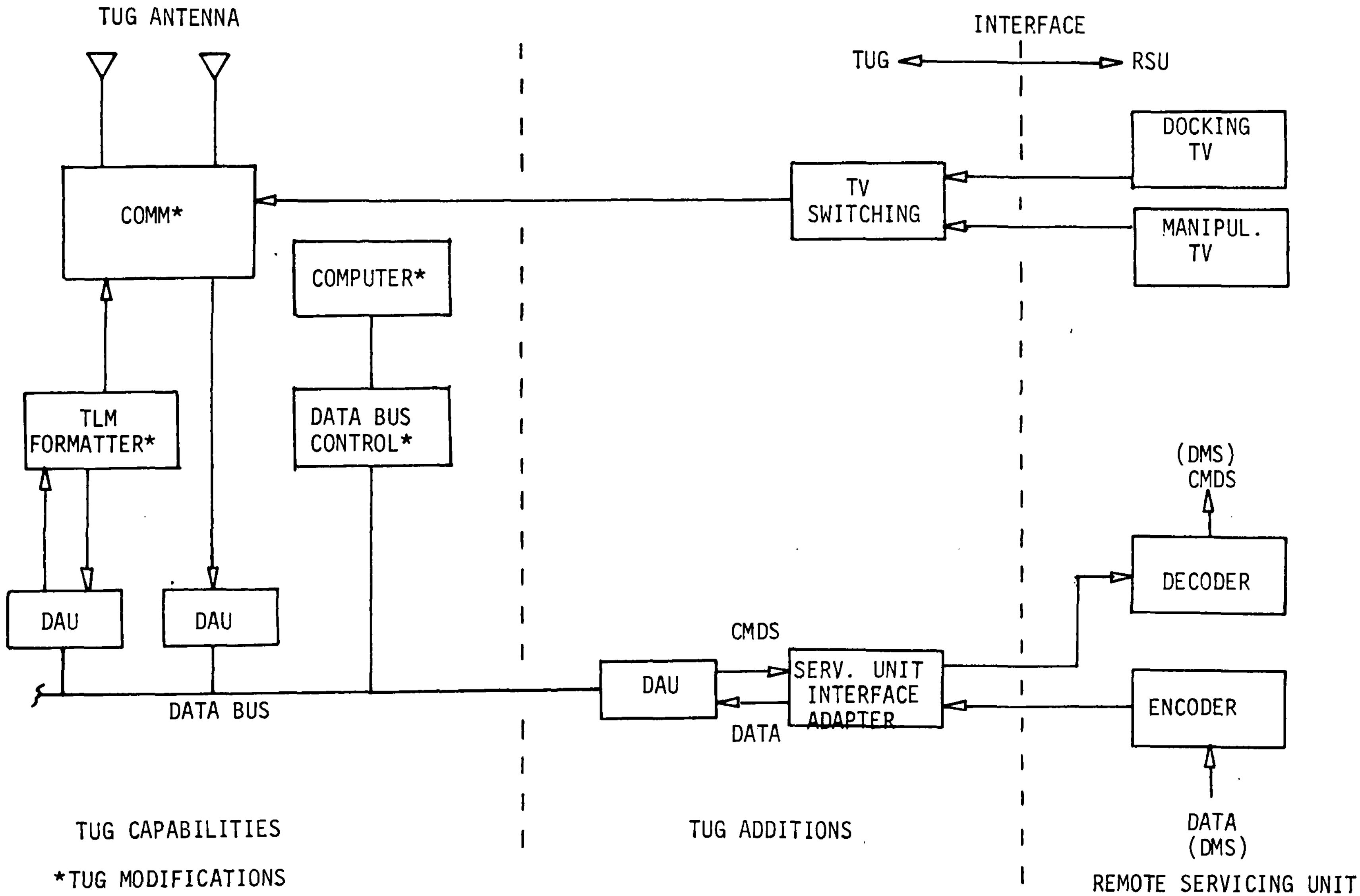


Figure 5.1.4. Data Relay through Tug Comm/DMS Subsystems

Table 5.1-2. Tug Communication Capability Versus RSU Requirements

Tug Capability	RSU Requirements
Telemetry - Downlink	Telemetry - Downlink
5 and 50 kbps expandable to 1 mbps	5 kbps - Adequate
Tracking	Tracking
PRN transponder to Ground Track	No requirement
Command/Control - Uplink	Command/Control - Uplink
Up to 2 kbps	Up to 2 kbps - Adequate
Video	Video
TV Docking/Inspection	TV Docking, Inspection and Module Replacement - Adequate

Table 5.1-3. Ground Communication Impact Summary

	Option / Impact Function	IMPACT: 1 Communications Direct	IMPACT: 2 Through Tug Communications	IMPACT: 3 Through Tug Communications & DMS
Service Unit	Weight	Maximum	Minimum	Minimum
	Power	Maximum	Minimum	Minimum
	Software	None	None	None
	Ground communication	Maximum	None	None
	Equipment cost	Maximum	Minimum	Minimum
	Equipment complexity	Minimum	Minimum	Maximum
	Ground control	None	None	None
	Interface complex	None	Minimum	Maximum
	Operations integration	Minimum	Minimum	Maximum
TUG	Weight	Minimum	Minimum	Minimum
	Power	Maximum	Minimum	Minimum
	Software	None	None	Maximum
	Equipment Cost	Minimum	Minimum	Maximum
	Equipment complexity	Minimum	Minimum	Maximum
	Ground control	None	None	None
	Interface complex	None	Minimum	Maximum
	Operations integration	Minimum	Minimum	Maximum

Table 5.1-4. Mission Power and Energy Requirements

Power Requirements	Missions 1 Placement	Missions 2 Servicing Only	Missions 3 Placement & Servicing	Peak Power Energy Requirements
Unmanned Tug				
watts	820	820	729	1400
kwhrs	44.5	87.5	104.4	104.4
Platform				
watts	250	250	250	250
kwhrs	13.3	3.0	16.3	16.3
Service Unit (SU)				
watts		300	300	300
kwhrs		26.2	31.3	31.3
Platform + SU				
watts	250	550	550	550
kwhrs	13.3	29.2	47.6	47.6
TOTALS				
watts	1070	1370	1370	1400
kwhrs	57.8	116.7	152.0	152.0

The preferred approach is to increase the tug reactant supply by approximately 10 pounds and thereby provide 152 kwhrs of electrical energy. Approximately 100 pounds of primary (single use) or 200 pounds of secondary (rechargeable/reusable) silver zinc batteries would be required to provide the same amount of electrical power utilization of deployed platform solar arrays during the transport phase would reduce the tug support requirements by 13.3 kwhrs, but the additional array structure that would be required to withstand the "g" forces (up to 1 g) encountered during tug delta-V maneuvers would be in excess of 400 pounds.

CONTAMINATION

Contamination of spacecraft equipment is becoming an increasingly critical problem, and equipment performance can be seriously affected if contamination is not minimized or eliminated. Based on previous spacecraft design and test experience, evaluations have shown that, even with extreme

care, critical surfaces can experience degradation of serious consequences. Critical surfaces include those which have demanding optical properties and which are cold and/or exposed to polymerizing and degrading space radiations. Examples of these surfaces are sensor lenses and mirrors, solar arrays, and space radiators used for thermal control.

Although all materials will outgas when subjected to a vacuum environment, the major condensible and optically degrading outgassed products will be from organic materials. There are many proposed transport mechanisms by which outgassed particles can reach critical surfaces: direct line-of-sight, single and multiple surface reflection, electrostatic, and "cloud" interactions. Of these, only direct line-of-sight will produce thick film (thousands of angstroms) deposits. For single or multiple surface reflections and electrostatic phenomena to produce thick film contamination would require a combination of poor materials selection and poor geometrical relationships. In general, these phenomena, plus cloud interaction, will produce only thin film (hundreds of angstroms or less) deposits. It is probable that most recent performance degradation of surfaces in flight is a result of thin film contamination and not thick film deposits.

Just the condensation of a thin organic film on a critical surface will, in general, have no effect on the characteristics. However as the organics of the film are exposed to the space radiation environment, the characteristics of the film will change. The film absorption characteristics will increase, and thus degrade thermal control coatings; the film opacity will increase and thus degrade the performance of lenses and mirrors. These are the changes which must be prevented and impose controls on volatile condensible materials (VCM).

Gross contamination will not be a major problem. The requirement for a cleanliness level of 100,000 or less, Federal Standard 209A, similar to spacecraft assembly areas, will be adequate to keep the spacecraft clean. This requirement would apply to the platform in general. Critical surfaces or sensors will require special provisions such as protective covers, shields, baffles,and selective installation locations.

A further requirement will be to limit the material selection to those materials that have a minimum VCM content. One standard that can be generally applied is to use materials that have less than 0.1-percent VCM and 1-percent total weight loss measured by the standard VCM technique, developed by Stanford Research Institute. It is recommended that this requirement be adapted for the shuttle, tug, and platform.

One unique potential contamination problem results from the proposed auto-remote servicing concept of platforms. After docking the platform is pivoted approximately 90 degrees from the tug centerline to permit inside changeout of replaceable modules by the manipulator. The hinge mechanism must be indexed midway between two sets of tug RCS thrusters. Otherwise direct tug RCS plume impingement on the platform would result.

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5.2 MANNED TUG INTERFACE CAPABILITY VERSUS PLATFORM REQUIREMENTS

Since there is no currently existing design concept for a manned tug, one was synthesized to permit the evaluation of interfaces with geosynchronous platforms. All equipment/provisions for the crew were considered to be a delta capability added to the unmanned tug. Also, it was assumed that the manned tug configuration would have at least the same payload support provisions as the unmanned tug. Table 5.2-1 summarizes the payload support capabilities of the synthesized manned tug and the interface requirements of geosynchronous platform for manned placement and servicing operational modes. Only those manned tug-platform interfaces (asterisked in Table 5.2-1) that are different than unmanned tug-platform interfaces will be addressed in this section.

DOCKING AND SEPARATION STRUCTURES

The differences between the unmanned and manned tug docking mechanisms are:

1. The unmanned tug with the RSN requires a 7-foot-diameter docking port to enable the manipulator and television to operate inside the platform for replacing modules.

2. For manned servicing, the docking mechanism must be compatible with the shuttle-orbiter 5-foot docking interface.

Evolution from an unmanned to a manned servicing system will require a docking interface that allows the smaller docking mechanism of the manned system to dock with the larger unmanned docking port of the platform. Figure 5.2-1 illustrates this adapter, which consists essentially of two concentric docking mechanisms. The inner system is approximately five feet in diameter, and is compatible with the space shuttle docking system. The outer mechanism is approximately seven feet in diameter, and mates with the docking port of geosynchronous platforms.

ELECTRICAL CONNECTOR

The preferred concept for the unmanned tug-platform electrical connector interface was a standardized configuration with better than 100-percent spare/growth capability. Signals for crew support functions during manned servicing operations (temperature monitor, fire alarm, humidity control, air circulation control, CO_2 partial pressure, contamination monitor, absolute pressure, etc.), are candidates for inclusion in the manned tug-platform electrical connector. However, if these functions are included in the connector this would imply that the necessary sensors are part of the basic platform configuration. Incorporation of such critical life support equipment in a platform that is normally unpressurized is not recommended. It could be several years between manned servicing visits to a platform, and the sensors in question would not be operated until the manned tug pressurizes the platform.

Table 5.2-1. Manned OTS Interface Capability Versus Platform Requirements

Interface	Manned tug capability	Platform interface requirement
*Docking/separation	5' shuttle compatible ring frame	7' to 5' ID ring frame adapter
*Electrical connector	Power, data, and control - general purpose	Power, data, and control - platform unique
Deployment	$\pm$25 nm alt., +0.1° incl., 0.1 g accel., 1 °/sec tip-off rate	Adequate
Stability and pointing	0.1°/sec and 0.2°	Adequate
Rendezvous within 54 nm	Ground tracking - passive payload	Adequate
*Terminal rendezvous	Laser or visual	Adequate - passive aids
*Predocking assessment	Platform to tug via ground	Adequate
*Docking	Laser or visual	Adequate - passive aids
*Atmospheric control	Platform pressurization and circulation	Adequate
Post-docking servicing	General-purpose DMS, monitoring and control	Adequate - special purpose DMS interfacing
Communication with ground	Voice - low data and command rates and TV	Adequate
*Power to platform	Up to 800 watts - 15 kwhrs	250 watts - 14 kwhrs, adequate

*Delta interface requirements/capability between unmanned and manned OTS

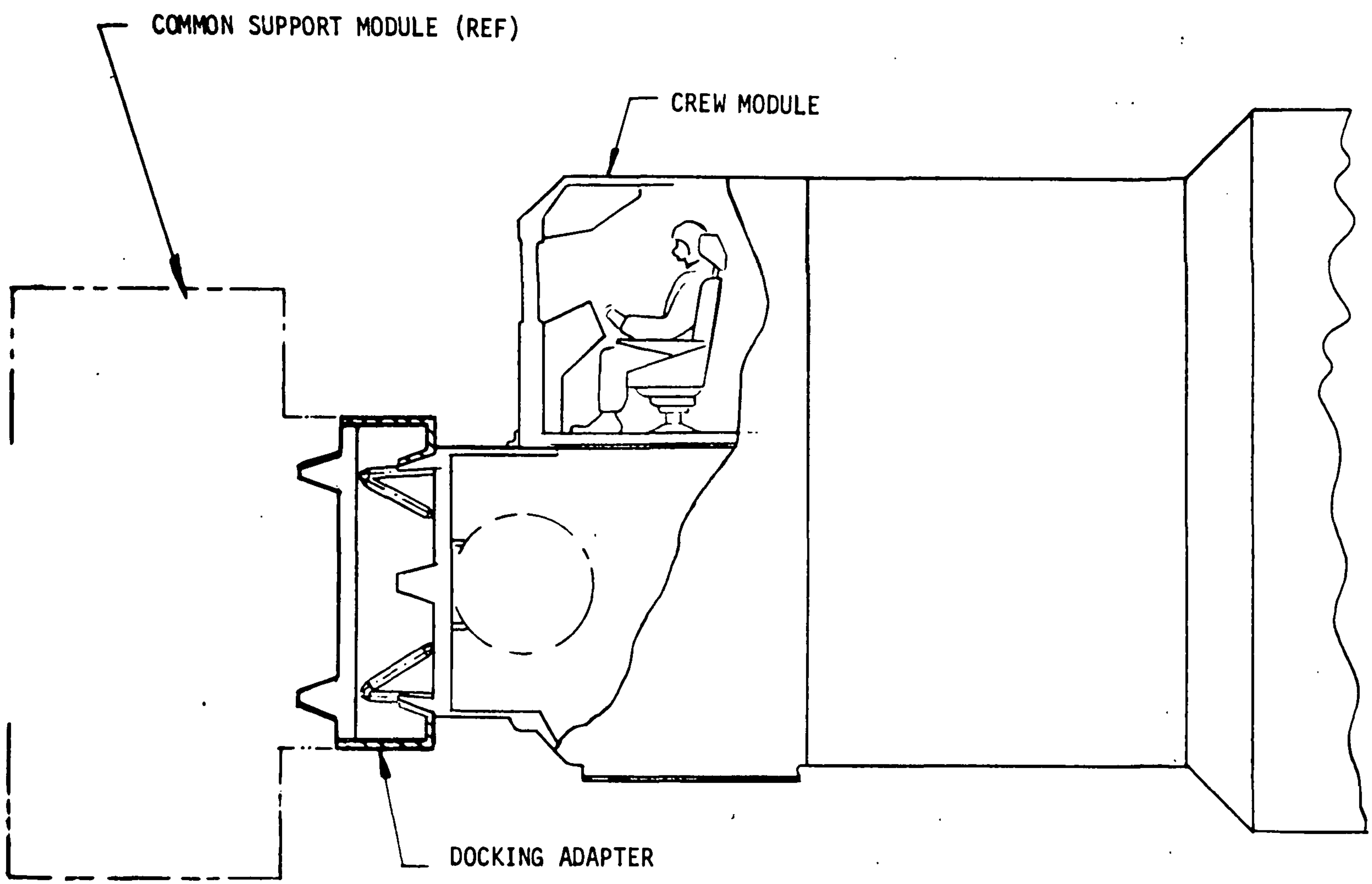

Figure 5.2-1. Dual Diameter Docking Concept

The preferred electrical interconnect made for manned servicing is to use the same connector as for unmanned servicing without any additional functions added. Figure 5.2-1 depicts the manned tug platform interface. Life support functional interconnects are to be accomplished by a temporary-manual installation of the necessary cable through the docking ports. Provisions must be incorporated in the manned tug for access to its life support control and monitor equipment.

TERMINAL RENDEZVOUS

The manned tug provides the added capability for visual location of the platform and thus eliminates the necessity of performing the maneuvers for a laser radar scan. Since target lock-on is accomplished in a relatively short time, the complex spacecraft search and acquisition portion of the terminal rendezvous sequence is eliminated.

PREDOCKING ASSESSMENT

The visual inspection portion of the platform predocking assessment will be accomplished by the crew rather than by ground viewing of the remote-controlled television. The data provided by man's added dimensions of depth perception and wide-angle viewing are more definitive than television for judging and assessing the physical condition of the platform before docking.

DOCKING

Auto-remote television docking is deleted on the manned tug and replaced by a crew visual docking technique similar to the Apollo method. The passive alignment standoff cross target, utilized for both visual or television docking, is located on the platform docking interface to permit its use with either the unmanned or manned tug configurations as shown in Figures 5.2-2 and 5.1-1. The laser radar system is available as an alternate docking method; it can be used in either manual or automatic mode of operation.

ATMOSPHERIC CONTROL

After docking, the platform must be pressurized with a habitable atmosphere, and circulation must be provided between the platform and the ECLSS subsystem on the manned tug.

A valve is provided at the hatch interface to pressurize the platform habitable volume. Instrumentation at the hatch interface is provided to ascertain the equalization and stabilization of pressure, and the presence of a safe-habitable atmosphere. Portable air ducting is provided between the tug-ECLSS and the platform to circulate the air. Storage of the atmospheric gases used to pressurize the platform is a delta requirement upon the tug. Platform atmospheric support provisions for a three-platform servicing mission will weigh about 117 pounds and require 5 ft^3 of storage space.

Space Division
North American Rockwell

Figure 5.2-2

5-25, 5-26

B CHG 5-2-73
A CHG 3-27-73

SCALE	DR. FENTRESS	SPACE DIVISION
1/40	DATE 2-27-73	NORTH AMERICAN ROCKWELL CORPORATION
	MODEL	12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA

MANNED REFURBISHMENT SYSTEM - GEOSYNCHRONOUS PLATFORM DEFINITION STUDY

2339-16B

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POWER

Power/energy profiles for the manned servicing and servicing/placement missions in Section 4.1 were developed. The combined three-platform servicing and platform emplacement mission required the maximum electrical support. But this mission required only 250 watts peak and 14 kwhrs of electrical energy. The significant decrease from the platform support requirements of the unmanned operational modes (700 watts 52 kwhrs) is because the RSU was the prime user of the electrical support in the unmanned mode (refer to Table 5.1-4).

Table 5.2-2 summarizes the manned operational mode electrical support requirements. The manned tug or crew module delta requirements are based upon Apollo life support equipment requirements.

Table 5.2-2. Manned Mission Power/Energy Requirements

	Manned Placement & Servicing	Manned Servicing Only	Peak Requirements
Unmanned Tug			
watts	820	820	820
kwhrs	106.1	88.5	106.1
Manned Tug Delta Power			
watts	850	850	850
kwhrs	106.3	88.0	106.3
Platform			
watts	250	250	250
kwhrs	14	3.0	14
TOTAL			
watts	1920	1920	1920
kwhrs	226.4	179.5	226.4

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5.3 PLATFORM/OTS TO SHUTTLE INTERFACE DESIGN ANALYSIS, AND TRADES

The purpose of this section is to discuss considerations and alternatives and arrive at recommendations regarding the interface design requirements between the platform and the space shuttle . Attached and separated operational interfaces (hardwire and RF link) are considered. The effort in this section was initiated by a review of MSC-06900, Space Shuttle Baseline Accommodations for Payloads, dated June 27, 1972, in order to understand the constraints and available services provided by the shuttle. Potential interface design alternatives were formulated and the impacts of each was evaluated. Results and recommendations as to the appropriate approach, and any special considerations,are presented below.

ASSUMPTIONS AND GUIDELINES

The following baseline shuttle capabilities were used to establish the platform-shuttle interface design requirements. The criteria reflect applicable portions of Section 2.200, Operational Interfaces of MSC-06900, identified above. The assumed interfaces for checkout, communications,and monitoring are shown in Figures 5.3-1 through 5.3-3.

Payload Checkout: Shuttle provides maximum flexibility and independence from shuttle checkout. Dedicated checkout computer, display, recorder, keyboard inputs, and extra/intravehicular (EVA/IVA) manual capabilities are available to check out payloads prior to deployment from the shuttle. Limited data can be forwarded to the ground by interleaving with shuttle data, or recorded as desired.

Payload Interfaces: Shuttle furnishes services through standard hardwire interfaces for power, communications, status monitoring, commands, test stimuli, data and other supports.

Safety Monitoring: Shuttle monitors and provides displays to the flight crew and mission specialists for those safety-of-flight parameters generated by payloads.

Command and Control: Payload operations may be commanded via the RF link from the ground or the shuttle payload monitor station. Shuttle has limited control capability to correct or circumvent catastrophic events and to activate and deactivate payloads.

Communications: Available communications from and to payloads via shuttle are summarized in Table 5.3-1.

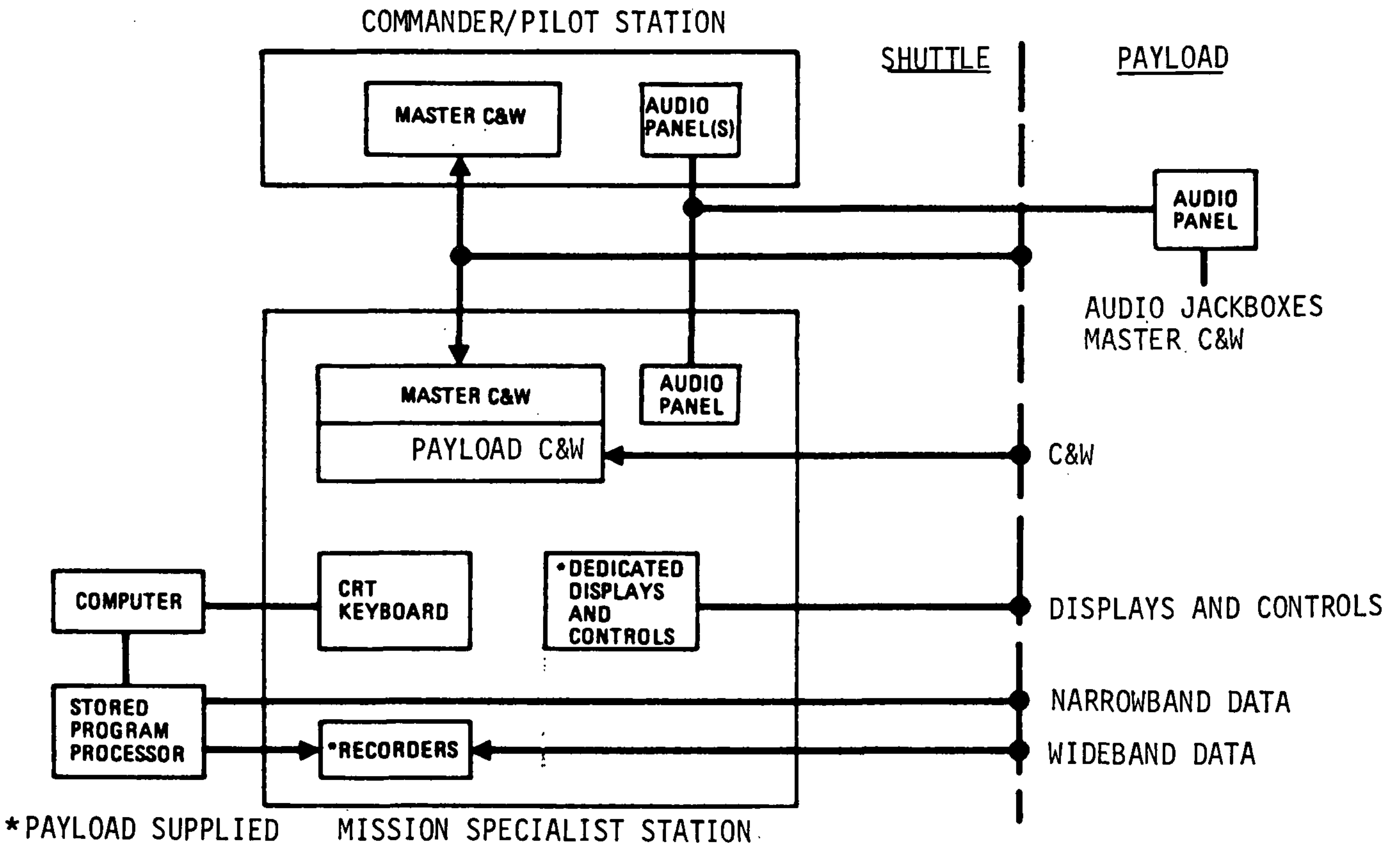

Figure 5.3-1. Mission Specialist Station Interfaces

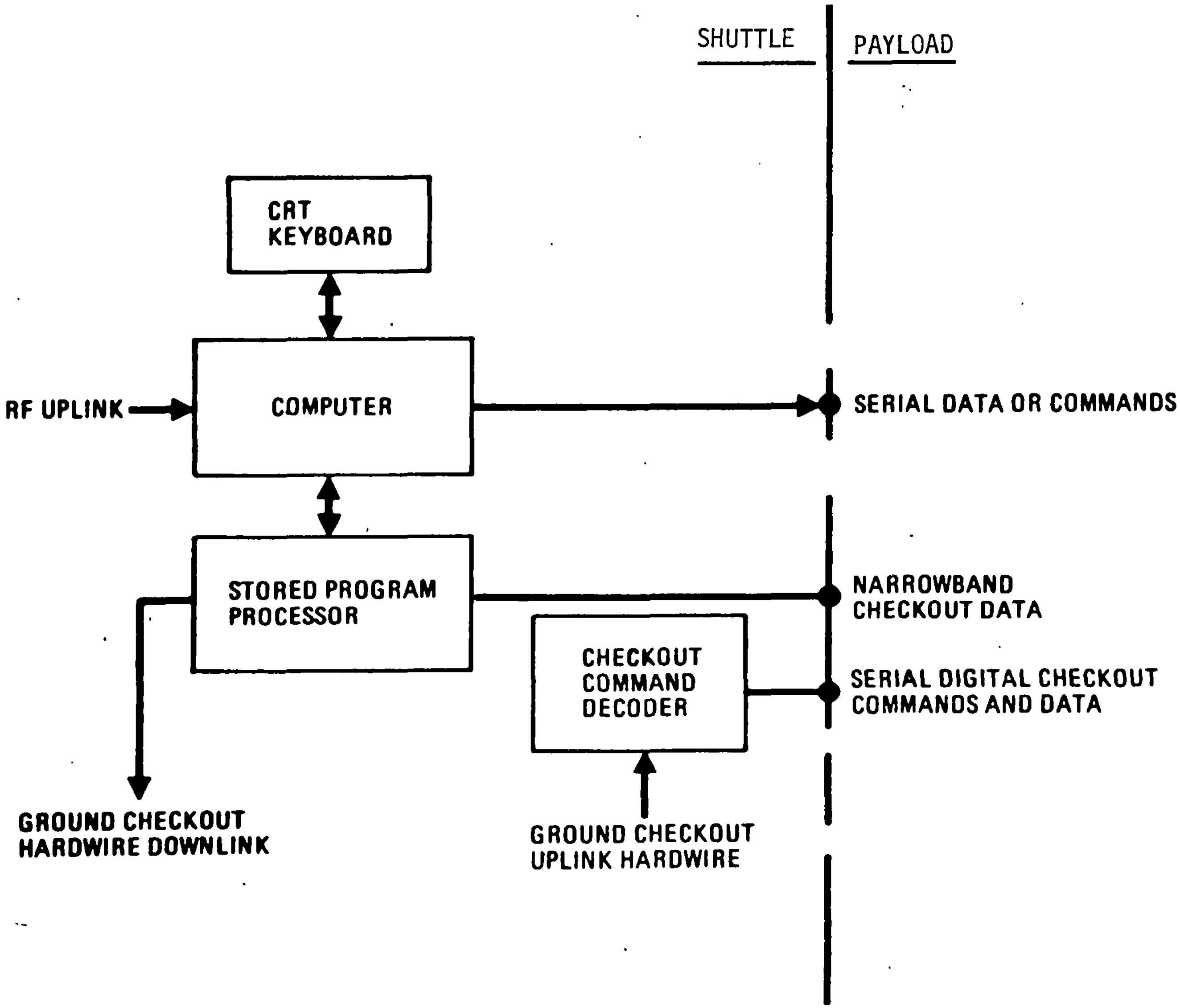

Figure 5.3-2. Shuttle-Payload Interface Checkout

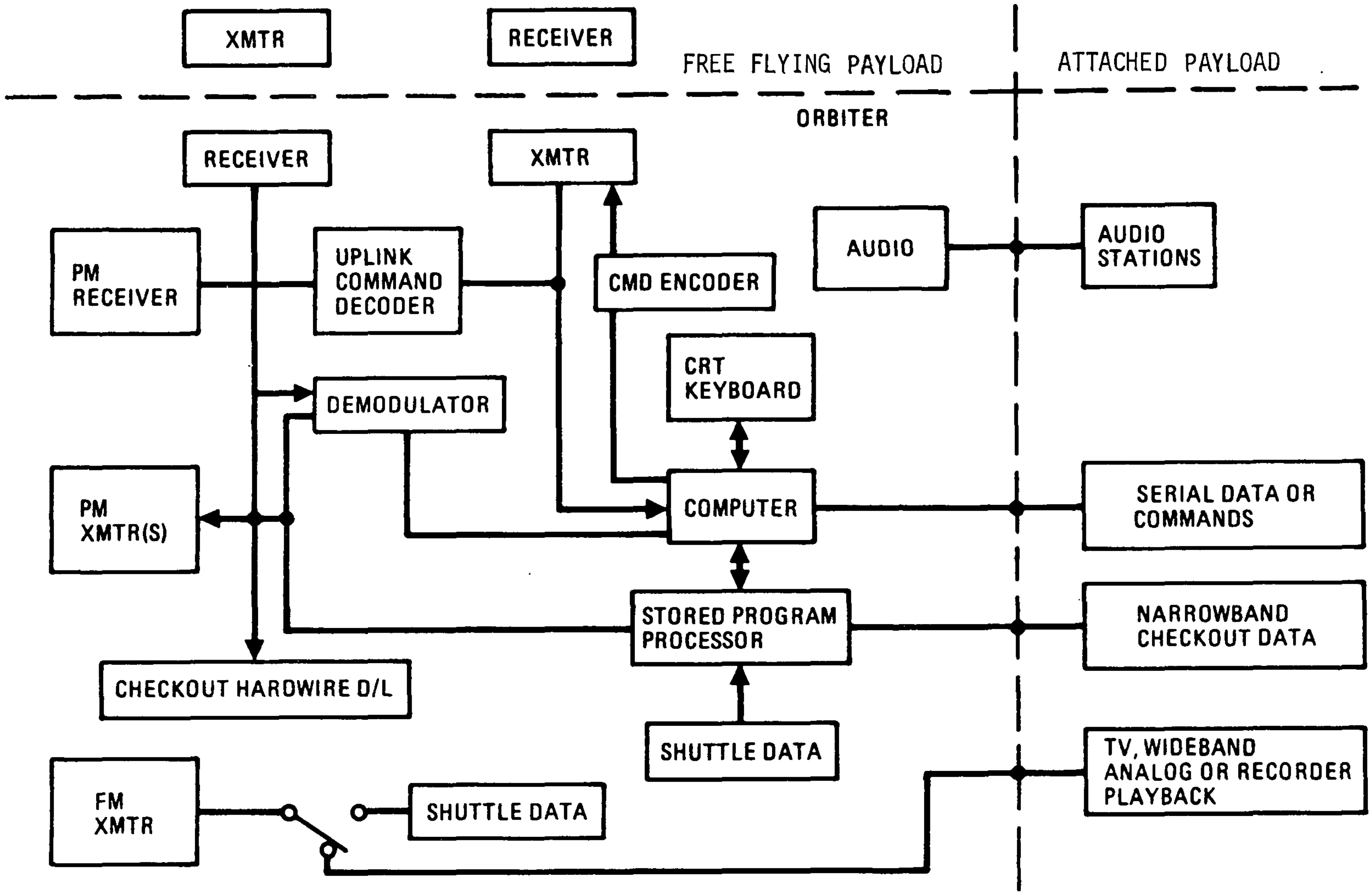

Figure 5.3-3. Shuttle-Payload Communication Interface

Table 5.3-1. Shuttle-Payload Communications Capability

Data Type	Interface	Digital Data Rate	Destination
Wideband analog or digital	Hardwire	256 kbps	Ground/recorder
Digital	Hardwire RF link	25 kbps	Ground Ground/displays
TV	Coax	--	Ground/displays
Uplink commands (Ground/Shuttle)	Hardwire and RF link	2 kbps	Tug-payload

As discussed in previous sections of this report, the tug and its attached payload require support (power, communications, etc.) in order to maintain operational temperatures and permit checkout. Monitoring for both functional checkout and safety purposes are required.

Mated tug/platform to shuttle operation must be considered from pre-launch integration through deployment and separation from the shuttle while on orbit. During this period,all checkout and communications with the ground, as well as environmental and power needs, are via the shuttle. The only significant interface options deal with whether the interface for the platform and the tug should be separately brought out to the shuttle or combined at the tug. Once the tug/platform separates from the shuttle, direct ground communications is possible.

TUG/PLATFORM TO SHUTTLE HARDWIRE INTERFACE

Figure 5.3-4 illustrates the three options for bringing out the platform and tug hardwire connections. Factors involved are as follows:

Option 1 Advantages

- Fixed locations for mating halves of the connector-umbilical system simplify design and coordination
- Easier single-step remating on orbit
- More working space to install connector system

Option 1 Disadvantages

- Wiring for the maximum platform signal requirement case is run for the full length of the tug. Design for easy changes may be desirable. A limitation on the number of separate checkout lines and high-frequency data channels exists.

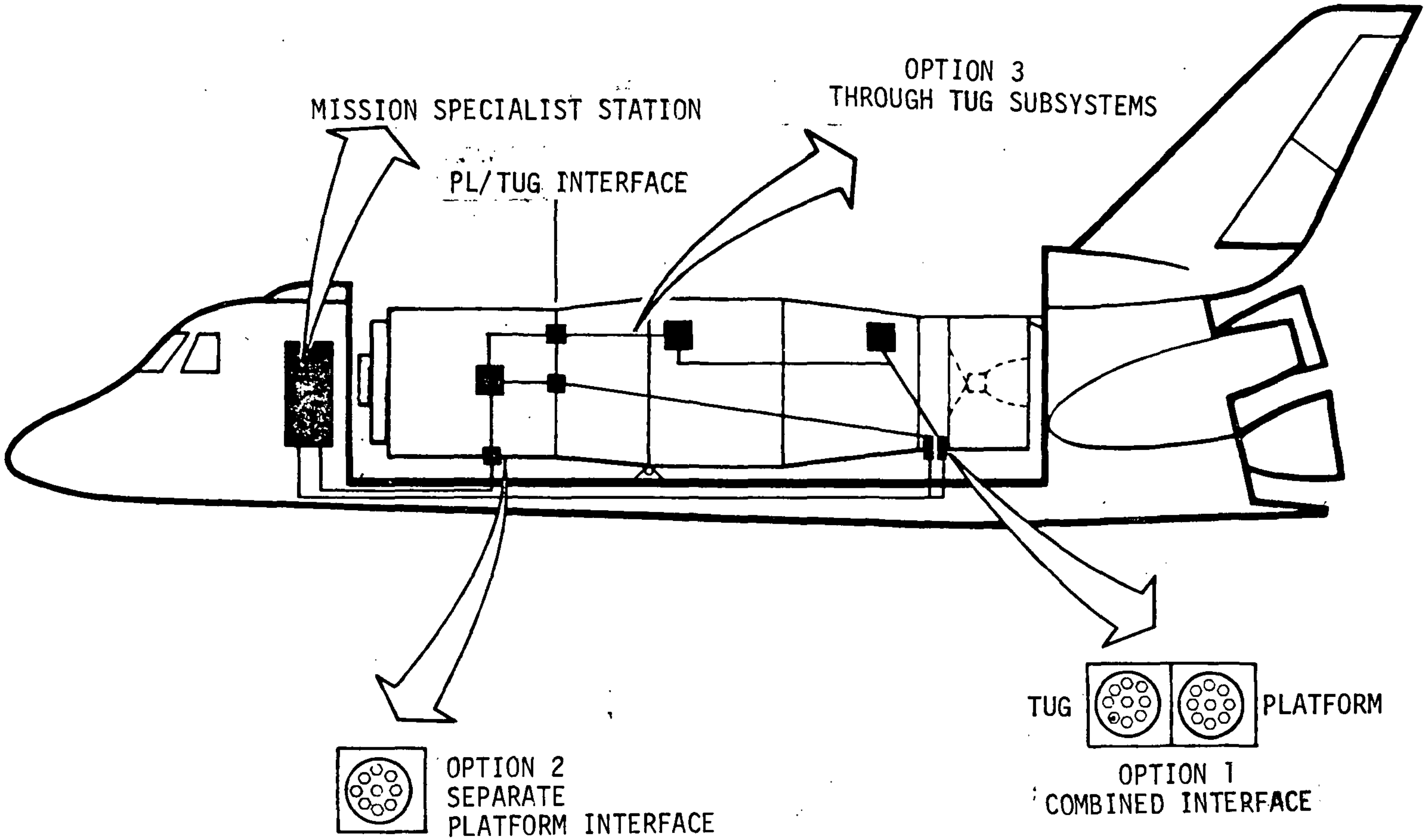

Figure 5.3-4. Tug/Platform to Shuttle Hardwire Interface Options

Option 2 Advantages

- No weight penalty on tug
- More flexibility by user agency to effect desired interface

Option 2 Disadvantages

- Limited space to install connector system
- Increased complexity in design/coordination to match connector halves and handle demating forces
- Difficult to demate and remate on orbit
- Redundant to servicing interface

Option 3 Advantages

- No discontinuity in transferring platform monitoring and control from shuttle to tug
- Utilizes platform activation/servicing interface
- Single location for tug/platform interfacing
- Single connector for both elements

Option 3 Disadvantages

- Tug communication, power, and data management subsystems must be activated and operating before platform can be monitored or controlled.

Option 3 was selected primarily because of the fewer number of transfers of the control and monitoring functions between interfaces and the reduced number of interfaces utilized in processing the platform.

TUG AND PLATFORM RF COMMUNICATION LINK WITH SHUTTLE

The requirement for RF communication between the tug and the shuttle, and the decision to modify and use the tug communication link for platform placement and servicing by adding a subcarrier to the existing system, provide the capability for the shuttle to transceive the information. A subcarrier demodulator and decoder would have to be added to the shuttle payload specialist station as part of the payload unique control equipment kit to permit processing of the data.

MANNED PLACEMENT MODE SHUTTLE INTERFACES

The manned servicing/platform placement mission presents a unique shuttle-platform interface problem. A dual shuttle launch is required to

deliver the two tug stages, crew module, and platform to low earth orbit. In order to maximize the shuttle and tug efficiencies the first stage tug and the platform are delivered in one shuttle; the second stage tug and crew module are delivered in the second shuttle. This concept maximizes the propellant loading in the tug stages and also maximizes the utilization of the shuttle cargo bay.

The on-orbit assembly procedure consists of mating the two tug stages together and then mating the platform to the crew module on the upper tug stage. As the platform is not attached to the first stage tug, a structural retention cradle is required in the cargo bay. Also a direct umbilical interconnect between the platform and the shuttle is required to perform monitoring and/or checkout of the platform prior to assembly with the crew module. The proposed concept to implement the platform - shuttle interface is similar to typical accommodations for multi-payload shuttle missions. A retention/support mechanism that is independent from the first stage tug support system is installed in the shuttle bay. The device should be designed for extraction of the platform from the cradle by the manipulator. The proposed electrical interconnect to the shuttle utilizes the same connector that will mate with the crew module.

6.0 SEP APPLICABILITY

As a further factor in the analysis and understanding of transportation system interfaces and requirements, the applicability of solar electric propulsion (SEP) was investigated. Since low-cost transportation for geosynchronous missions will continue to be of growing importance in the shuttle era of the 1980's, efficient high-energy upper stage systems are being seriously investigated. Among these systems is the Solar Electric Propulsion Stage (SEPS). Although previously considered primarily for interplanetary flight, SEPS is applicable to the geo-orbital regime. The use of a geosynchronous SEPS (called Geoseps) in conjunction with the shuttle and tug was investigated in Reference 6-1. It is the purpose of this analysis to evaluate the applicability of Geoseps to the geosynchronous platform programs defined in Volume VI utilizing the stage configuration and performance data presented in Reference 6-1.

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6.1 GEOSEPS DEFINITION

The Geoseps has a unique combination of a very high I_{sp} and a high-density mercury propellant. The nominal I_{sp} of 3000 seconds and the propellant density of 13.5 lb/cu ft result in a design in which propellant and tankage are not dominant elements, as they are in chemical propulsion stages. This feature, along with easy space storage of liquid mercury, permits Geoseps to operate as a space-based interorbital transportation system capable of conducting several round-trip sorties between intermediate orbits and synchronous orbits with a single load of propellant. The Geoseps can also operate in the ground-based mode (in which the Geoseps is returned to ground after each sortie) and in a "quick-up" mode (in which fast payload delivery is achieved). Furthermore, the Geoseps can perform large rendezvous phasing maneuvers and other orbital operations with little propellant usage and without propellant boiloff problems.

CONFIGURATION FEATURES

The Shuttle/Tug/Geoseps transportation system configuration is shown in Figure 6.1-1. A fully fueled Geoseps is a 6000-pound stage carrying 3300 pounds of liquid mercury propellant. The Geoseps requires about 10 feet of the shuttle's 60-foot cargo bay. The remaining length is available for the tug and payloads (a 35-foot high-technology tug is shown in the figure). Once a Geoseps is operating in the interorbital mode, the entire shuttle cargo bay is usable by the tug and payloads for the next several sorties, until the next Geoseps is to be delivered to orbit.

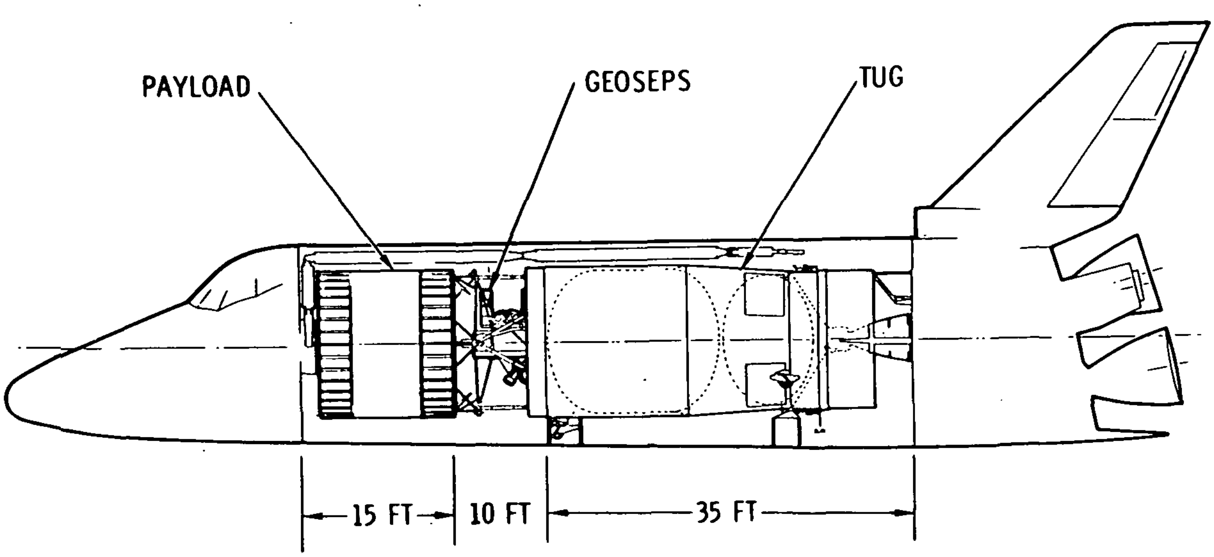

Figure 6.1-1. Transportation System Configuration

The basic Geoseps design is depicted in Figure 6.1-2. The key elements of the Geoseps are the large deployable solar arrays, power conditioner panel, ion thruster array, central compartment, and docking mechanism. The solar arrays generate an initial total power of 25 kilowatts at 200 to 400 volts. Of this a maximum of 21 kilowatts is processed by seven of the eight power conditioners to operate seven 30-cm-diameter thrusters at an I_{sp} of 3000 seconds. The Geoseps is equipped with nine thrusters to provide the maximum thrust life of the Geoseps by sharing the usage uniformly among all thrusters. It is 206 feet from the tip of one solar array to the tip of the other solar array.

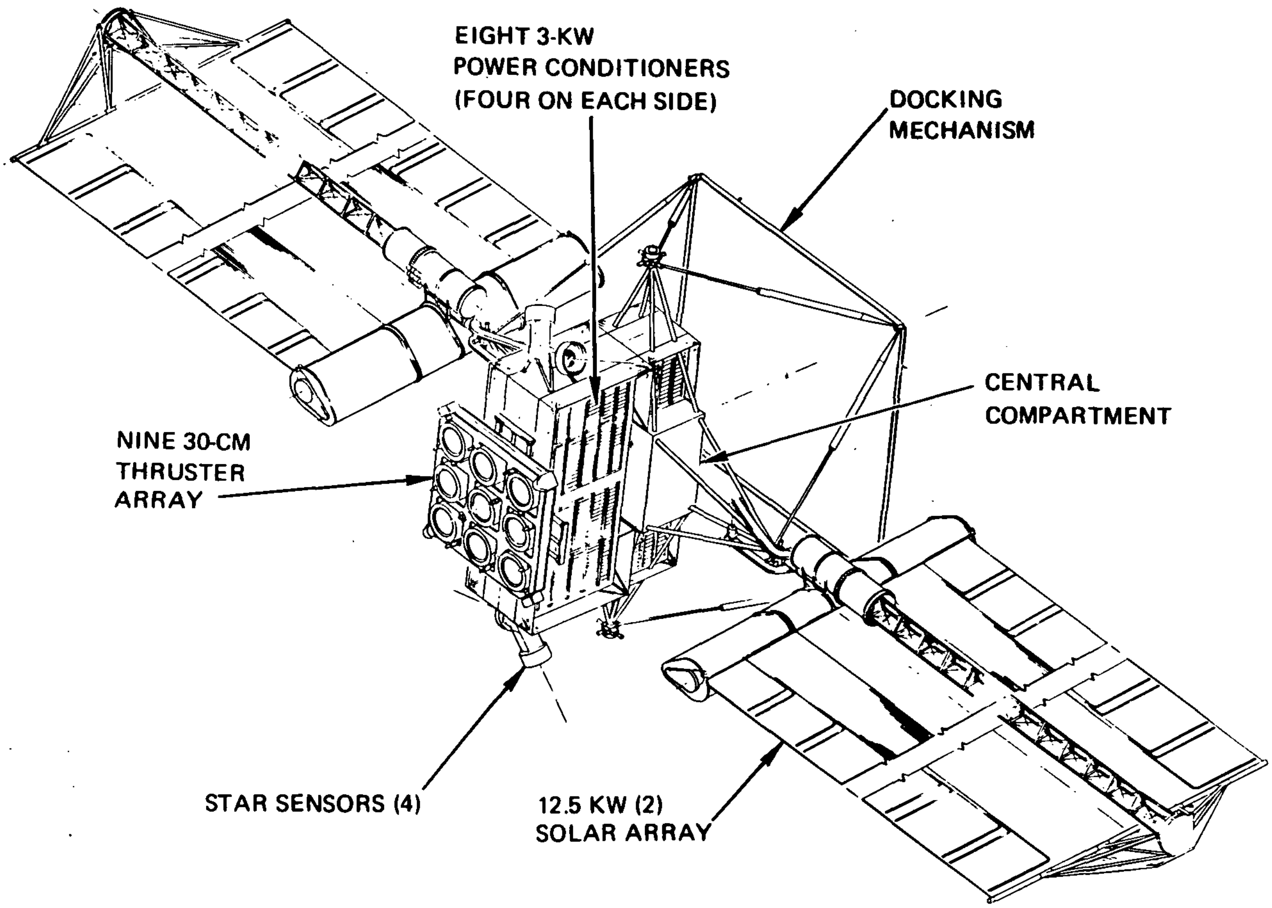

Figure 6.1-2. Geoseps Configuration

The ion thruster array provides three-axis attitude control in addition to primary propulsion. The thrusters are mounted on a translator, a mechanical tray capable of translating in two axes. This enables control of the net thrust about the Geoseps/payload center of gravity, with resulting control about two axes. In addition, roll control can be achieved by single axis gimbaling of thrusters.

During the thrusting phase, the solar arrays are sun-oriented and the central body of the Geoseps is rotated (relative to the solar arrays) to achieve the desired thrust direction. The power conditioner panels are mounted in a back-to-back arrangement and are inherently shaded from the sun when the solar arrays are sun-oriented.

The central compartment contains the communication, data handling, attitude control, command computer, and electric power subsystem equipment. Television equipment for rendezvous and docking via ground operator is located at the forward end. The 3300 pounds of Mercury propellant are stored in four 15-inch diameter tanks also located in the central compartment. The four star sensors used for guidance and navigation are optimally located to satisfy pointing and sun clearance requirements.

The docking mechanism is attached to the central compartment by the four support structures. Two of the support structures also support the deployed solar arrays. The two low-gain antennas are mounted on the other two. Reaction control thrusters are integrated with these support structures.

MISSION AND PERFORMANCE CHARACTERISTICS

The most effective use of Geoseps for geosynchronous missions is in conjunction with a high thrust chemical stage such as a reusable tug. Direct ascent from the shuttle orbit using Geoseps alone would require extremely long mission times (several hundred days). Also, lengthy passage through the high intensity Van Allen radiation belts would result in severe solar cell degradation.

The tug is used to deliver the Geoseps and payload to an intermediate orbit called the changeover orbit from which the Geoseps propels the payload into the desired geosynchronous orbit. The overall transfer orbit geometry is shown in Figure 6.1-3. Total trip time is shortened considerably (by more than 100 days) and the passage time through the Van Allen belts is minimized. The changeover orbit parameters are optimized with respect to the tug and Geoseps performance capabilities.

After placing the Geoseps and payload into the changeover orbit, the tug returns immediately to the shuttle while the Geoseps and payload begin the ascent to geosynchronous orbit. Once boosted into the changeover orbit by the tug, the Geoseps performs a series of round trips between changeover and geosynchronous orbits exchanging returned payloads for new payloads to be delivered. After initial delivery of the Geoseps, subsequent tug sorties carry only payloads so that full advantage is taken of the tug and Geoseps performance capabilities. After depletion of its propellant (536 days of thrusting operations), the Geoseps may be abandoned in space or returned to the ground for refurbishment.

Figure 6.1-4 presents a schematic representation of the reference interorbital Geoseps mission derived in Reference 6-1. This mission comprises five round trips with the Geoseps abandoned in space after propellant depletion. The changeover orbit is different for the first and last sorties because a Geoseps is carried on these legs in addition to payloads being transported to and from geosynchronous orbit. Table 6.1-1 presents the event

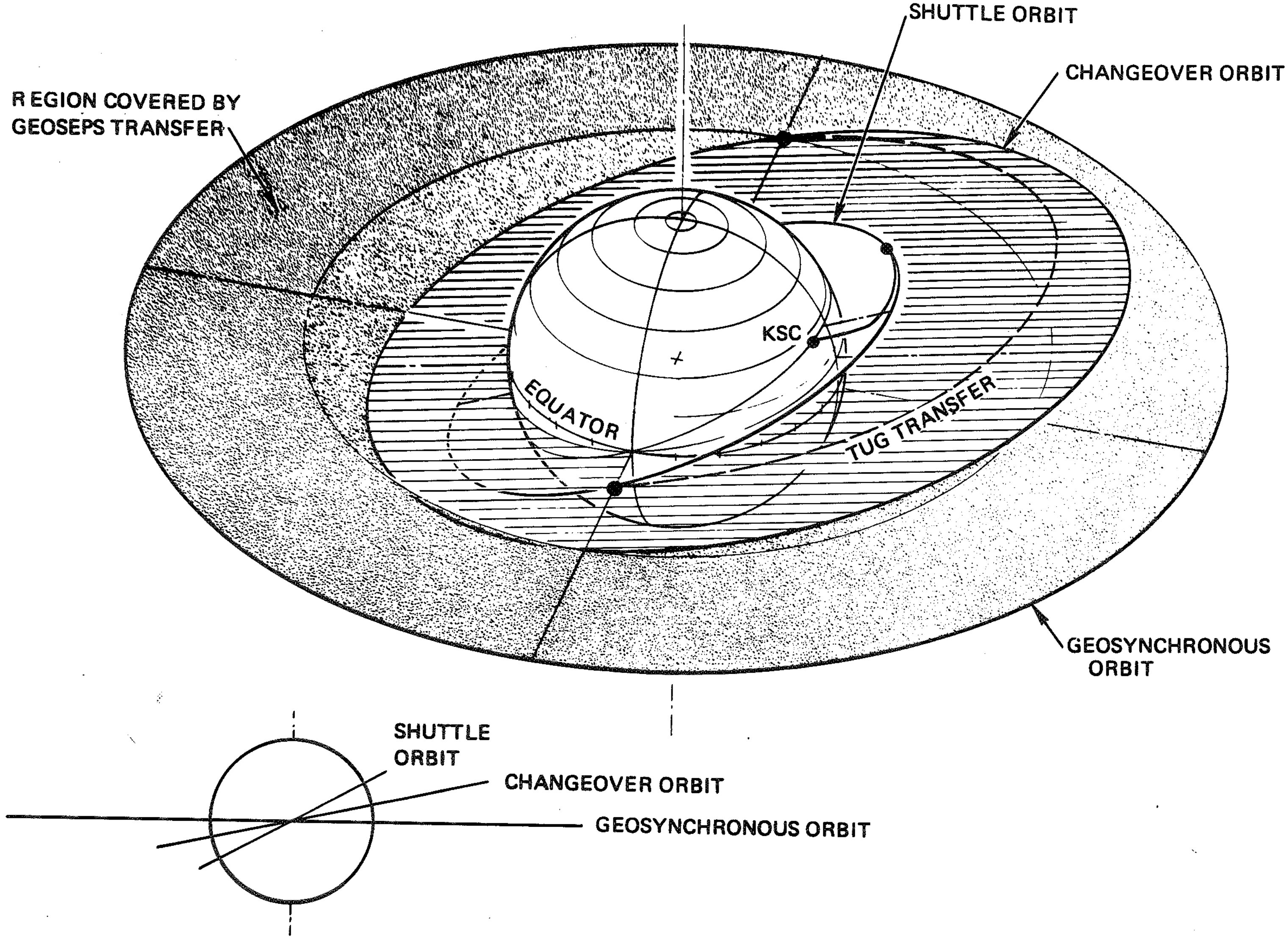

Figure 6.1-3. Geoseps Basic Orbit Transfer Profile

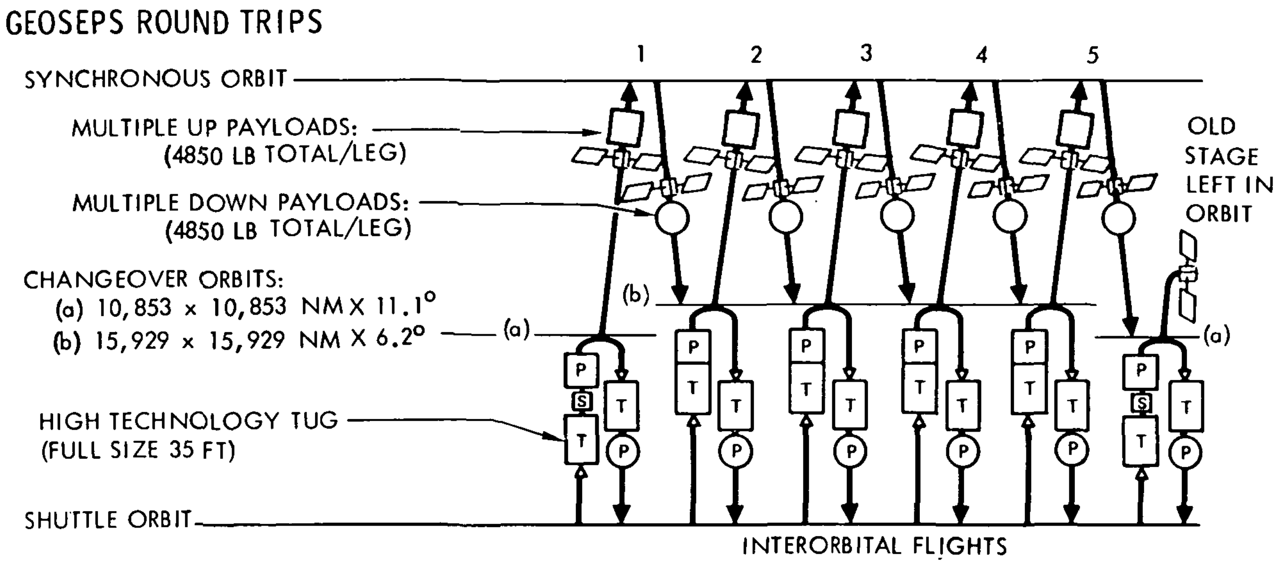

Figure 6.1-4. Reference Mission Schematic

timeline for this mission. Note that the Geoseps transit times vary as propellant is depleted, and with the planned lower changeover orbit on the first and last legs.

This reference mission results in a round trip payload capability of 4850 pounds (on each of five trips). Deployed and returned payloads need not be equal, however, and their magnitudes are also dependent upon the number of round trips being flown. Figure 6.1-5 presents the delivered and returned payload weight combinations for missions with up to 10 round trips flown within the 536-day thrusting capability of Geoseps.

The performance characteristics of the reference mission stages are given in Table 5.1-2. The analyses in Reference 6-1 investigated Geoseps in conjunction with four tug configurations ranging from a high-technology, cryogenically fueled version to a low cost, storable propellant concept. The use of the high technology tug not only provides a straightforward comparison with the platform programs derived in this study, which also used this baseline, but also exploits to the fullest the particular advantages of long lifetime and low propellant consumption of Geoseps. Hence, it is the configuration utilized here in assessing the applicability of Geoseps to geosynchronous platform programs.

Table 6.1-1. Geoseps Interorbital Reference Mission Timeline

No.	Event	Event Duration — Round Trip (Sortie) Number 1	2	3	4	5
1	Shuttle boost to 100 n mi orbit	0.8 hr				
2	Deploy tug/Geoseps/payload and coast	3.3 hr				
3	Tug ascent to changeover orbit	4.0 hr				
4	Deploy and ready Geoseps and payload	2.1 hr				
5	Geoseps ascent (days)	107	46	43	41	38
6	Payload deployment	4.5 hr	→	→	→	→
7	Rendezvous with down payload (days)	2	→	→	→	→
8	Payload docking	4.0 hr	→	→	→	→
9	Geoseps descent (days)	47	44	42	40	80
10	Payload exchange in changeover orbit	4.3 hr	→	→	→	→
	(Return to 5 for next sortie)					
11	Geoseps disposal, last sortie					1.0 hr
	Mission time (days)	157	249	337	421	541

(Geosynchronous placement and retrieval with Geoseps exchanging payloads at tug/Geoseps changeover orbit)

Payload = 4850 pounds each round trip

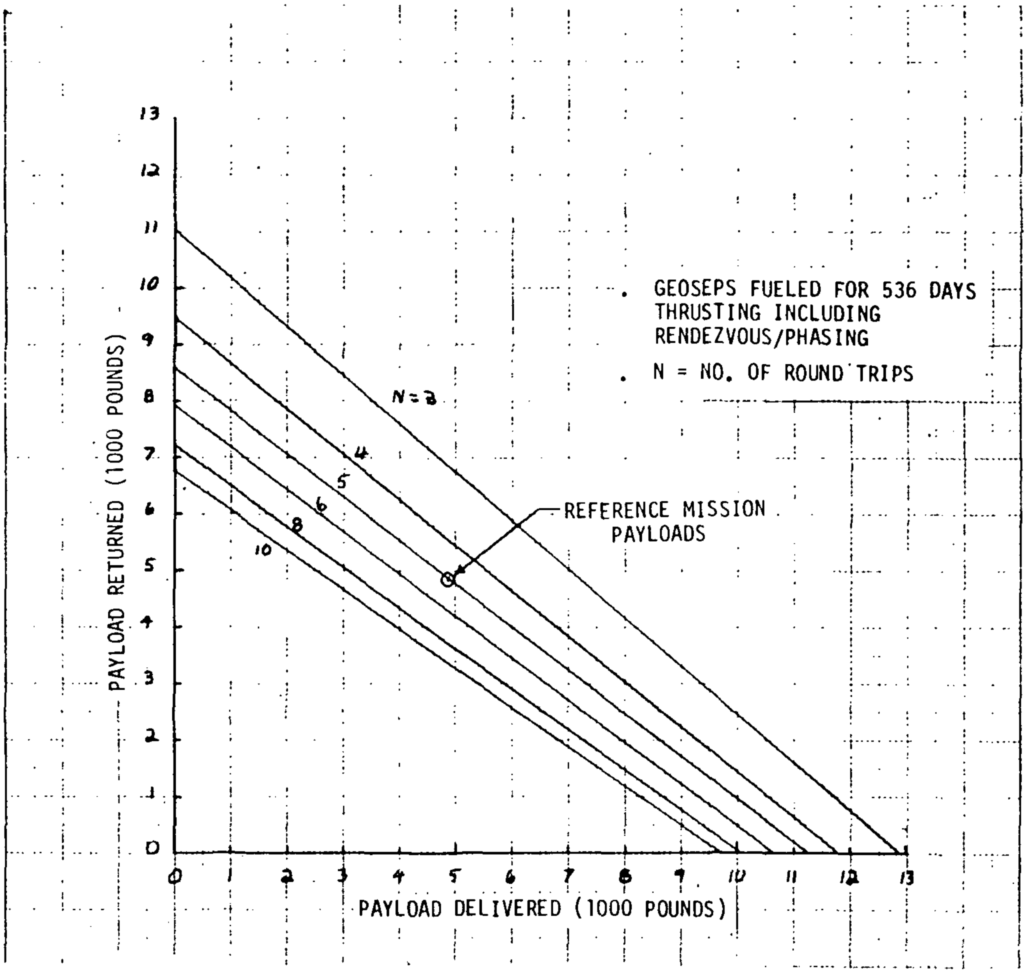

Figure 6.1-5. Payload Performance Envelope for Reference Mission

Table 6.1-2. Stage Performance Characteristics

SHUTTLE	
Net usable weight to orbit (excludes tug/shuttle interface mechanism)	63,500 pounds
TUG	
Stage (empty)	6,173 pounds
Usable propellant	56,000 pounds
Other consumables	780 pounds
Specific impulse	470 seconds
GEOSEPS	
Stage (empty)	2,690 pounds
Usable propellant	3,170 pounds
Thrust	0.206 pounds
Specific impulse	3,000 seconds
Thrust lifetime	536 days

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6.2 GEOSEPS APPLICABILITY ASSESSMENT

The principal advantages attributed to Geoseps are its wide flexibility for delivery of varied payloads to geosynchronous orbits, up to 10,000 pounds and even more with special flight modes. Many combinations of trip time and flight mode are possible which result in highly flexible payload delivery/ return capabilities. These would permit delivery and on-orbit servicing operations over very wide orbital sectors compared to the more restrictive conditions imposed by the shorter mission life and more limited delta-V capabilities of chemical stages. Although there would be added development costs, this combination of high performance and operational flexibility offers a strong potential for reduced transportation costs through reduced numbers of shuttle/tug flights.

Although not identified in the Geoseps study (Reference 6-1), another apparent potential advantage of Geoseps would be to utilize electrical power from its solar arrays to perform on-orbit servicing operations. These would occur during non-thrusting periods where thruster power (more than 20 kw) could be made available for other uses. Appropriate payload interfaces and other modifications to the Geoseps would be required.

Each of the above potential advantages was analyzed in the context of geosynchronous platform programs. The results of these analyses are discussed below.

LARGE PAYLOAD CAPABILITY

As indicated in the paragraphs above, the shuttle/tug/Geoseps provides the capability to deliver payloads in excess of 10,000 pounds to geosynchronous orbit. This is substantially greater than the capability of the tug alone, even for the high technology tug (P/L 8500 pounds). However, as shown in Table 6.2-1, the largest platforms in the inventories developed during this study are less than 8500 pounds. Thus, on the sole basis of large payload delivery capability, the use of Geoseps for geosynchronous platforms cannot be justified. Several of the platforms are very close to the 8500-pound tug capability, and weight growth in these platforms and/or less than anticipated tug performance could result in the need for additional delivery capability. This need would be further heightened if some version of the low cost tug with less performance instead of the high technology tug was introduced into the space transportation system. Compromises in platform configurations could be made to reduce weight and be compatible with lower tug performance. However, these trades are beyond the scope of this analysis. Thus, it is concluded that Geoseps is not required with the high technology tug, but may be required with reduced tug performance (on the basis of payload delivery requirements alone).

Table 6.2-1. Geosynchronous Platform Weights

Platform Type	Weight (lb)
Communications relay platforms	2759 to 4005
TDRS platforms	2651
Earth observations platforms	8496
Astro-physics platforms	4102 to 8499
Navigation and traffic control platforms	2799

GEOSEPS COMPATIBILITY WITH ON-ORBIT SERVICING

The principal factor governing Geoseps compatibility with on-orbit servicing is trip time. As shown previously in Table 6.1-1, trip times vary from 81 days to 154 days for the five round trip reference missions. These long trip times virtually eliminate any consideration of Geoseps in conjunction with manned servicing modes.

Long trip times favor scheduled over unscheduled maintenance. The Geoseps capability for widely spaced servicing is particularly attractive with platform programs, since up to 90 percent of the missions involve servicing. Although scheduled maintenance is typically more expensive than unscheduled, when replacement hardware costs are combined with overall logistics costs, the ostensible advantages of unscheduled maintenance may be lost. Specifically, the greater flexibility required for the peak demands associated with unscheduled maintenance results in greater fleet size for shuttle/tug operations. This problem is increased by the longer trip times (of factors of 10 to 20) necessary with the use of Geoseps.

Another deterring factor to the use of Geoseps is the more complex operations which would be introduced. Some added monitoring of mission progress would be required because of the extended trip times, but of particular concern is the addition of a payload exchange operation between the tug and Geoseps. Some means must be provided for the down payload to be transferred to the tug and the up payload to the Geoseps. This affects both delivery and servicing type missions. The Geoseps feasibility study of Reference 6-1 utilized a free-flying payload concept as depicted in Figure 6.2-1. The down payload is activated for free flight, the up payload is docked to the Geoseps and the down payload is then picked up by the tug and returned to the shuttle. This concept applies principally to the handling of satellite-type payloads and cannot be applied to payloads compromising replaceable modules for servicing misions. Those defined in this study do not have the capability for free flight.

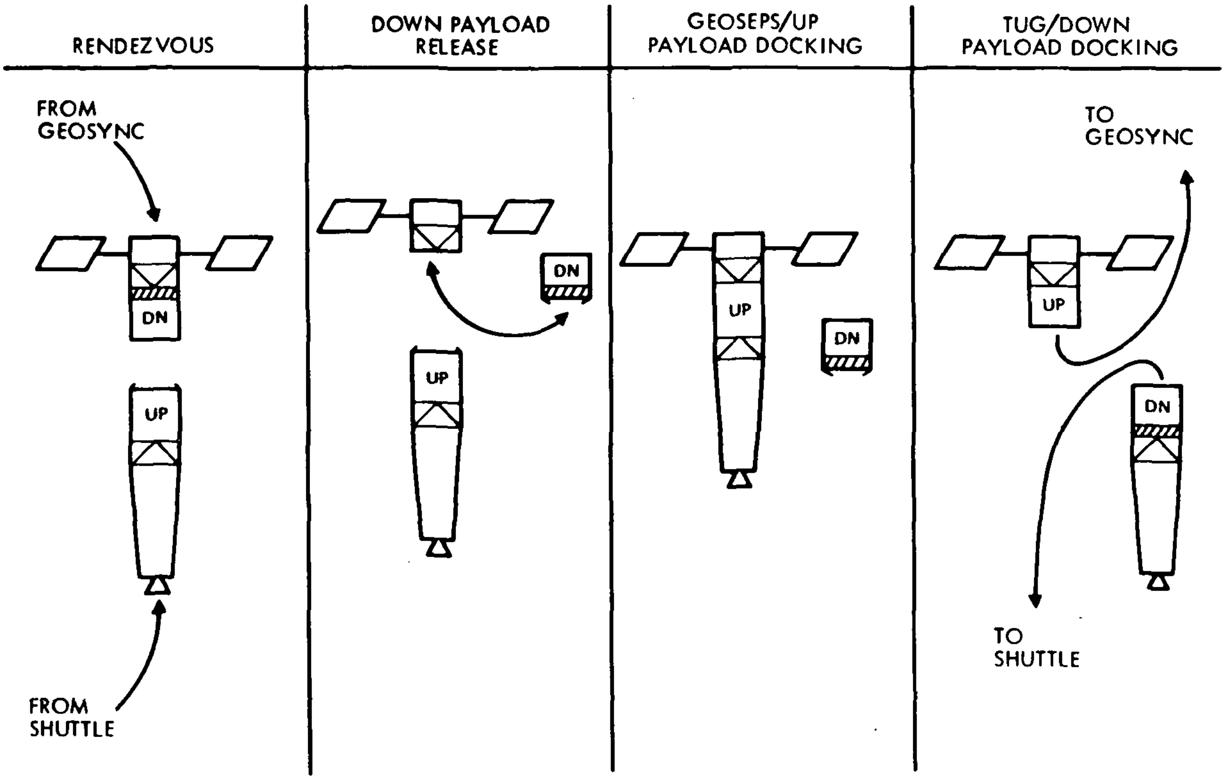

Figure 6.2-1. Payload Handling Concept (Reference 6-1)

An alternate approach to free-flight payload exchange is required for servicing-type missions. Several possibilities are feasible, including:

1. Geoseps/tug stationkeeping with manipulator exchange of payloads.
2. Rigid tug/Geoseps attachment with manipulator exchange of payloads.
3. Dual docking mechanisms on all transferred elements and on either the tug or Geoseps.
4. Space-based servicing unit (attached to Geoseps) and with individual module exchange performed by the manipulator on the servicing unit. (This would not satisfy the requirements associated with combined delivery and servicing.)

On the basis of design simplicity and probable lower weight penalties, Options 3 and 4 or combination thereof appear to best meet the needs of servicing and servicing plus placement-type missions. Even with these options, weight penalties would be imposed on the transportation system along with relatively complex operations involving multiple disconnect/connection functions and their related risk factors.

Thus, while Geoseps offers the potential advantages of wide-spaced servicing capability, long life on orbit, and could provide electrical power for on-orbit servicing operations, there are several important drawbacks to its use. Long trip times are incompatible with manned servicing modes, and they also compound the problems of fleet utilization associated with unscheduled maintenance. Finally, the use of Geoseps introduces a complex payload exchange operation with attendant risks and logistics performance penalties. Additional analyses, beyond the scope of this study, are required to fully evaluate these effects.

ECONOMIC FACTORS

The analyses in Reference 6-1 showed that savings in recurring transportation costs between 11 and 20 percent for single and multiple payload delivery cases could be achieved with the Geoseps in conjunction with the high technology tug. The following brief analysis focuses on specific factors related to platform operations which bear on the realization of these potential cost advantages.

Table 6.2-2, taken from the programmatic data in Volume VI, shows a reference case of platform delivery/servicing requirements for the 10-year program used in the evaluation analyses. Both remote and manned servicing modes are shown for the case, with 50 percent module changeout every two years. Since manned servicing modes are incompatible with the Geoseps long trip times, only the remote servicing mode will be considered here. A total of 56 shuttle flights is shown, with a maximum flight rate of 10 flights per year. Transportation efficiency, the ratio of actual payload delivered to the total payload capability of the shuttle/tug system, ranges from 33 to 72 percent during the 10-year program. Most missions are flown with the shuttle partially empty due to several factors which are: volume constraints in the cargo bay, limits on how many payloads are scheduled to be delivered to a specified orbital location, or the discrete nature of platform weights; i.e., one platform does not fill the shuttle, but two platforms would exceed its capacity.

If it were assumed that the increased performance and flexibility introduced through the use of Geoseps would improve the transportation efficiency of the shuttle/tug to 100 percent, significant cost savings could result. The average efficiency over the 10-year program is 58 percent, which if increased to 100 percent could reduce the number of shuttle tug flights from 56 to 33. The 23 fewer flights represent a potential cost savings of $287.5M at $12.5M per flight.

These potential cost savings must be adjusted to account for several offsetting factors: payload penalties associated with the payload exchange mechanism, additional platform servicing units required because of long trip times, and the developmental and recurring costs for the Geoseps. The effects of these factors were initially analyzed by simple application of the five round trip reference missions depicted in Reference 6-1. However, preliminary results revealed that direct application of this mission would not fully exploit the true potential of Geoseps to support geosynchronous missions and thus, would not provide a fair evaluation of its performance.

Table 6.2-2. Platform Delivery/Servicing Summary
(50 Percent Spares per Two Years)

		81	82	83	84	85	86	87	88	89	90	TOTAL
	PLATFORMS DELIVERED	8	1	7	-	1	1	-	-	-	-	18
	VISITS											
	UPDATE AND/OR SERVICE	-	2	2	2	1	2	2	2	1	3	17
	SERVICE	-	-	6	1	14	1	14	2	15	2	55
	Σ(DELIVERIES + VISITS)	8	3	15	3	16	4	16	4	16	5	90
	$W_{PL\ UP}$ (LB)	32,950	6,890	29,860	2,407	18,274	4,360	17,428	3,180	16,560	3,050	134,959
	$W_{PL\ DOWN}$ (LB)	0	150	8,650	2,638	15,174	2,508	17,287	2,795	16,560	2,918	68,680
	ΣW_{PL} (UP + DOWN)	32,950	7,040	38,510	5,045	33,448	6,868	34,715	5,975	33,120	5,968	203,639
REMOTE	NUMBER OF SHUTTLE FLIGHTS	8	2	10	2	8	3	9	2	9	3	56
	W_{PL} CAPABILITY (LB)	60,402	11,568	67,224	7,955	46,304	13,790	56,917	10,291	56,898	17,782	349,131
	EFFICIENCY (PERCENT)	54	61	57	63	72	50	61	58	58	33	58
MANNED	NUMBER OF SHUTTLE FLIGHTS	8	3	15	4	17	5	14	4	16	6	92
	W_{PL} CAPABILITY (LB)	60,402	14,920	72,106	17,513	64,982	22,084	57,515	10,091	57,666	20,354	397,633
	EFFICIENCY (PERCENT)	54	47	53	29	51	31	60	59	57	29	51

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Rather than apply the up-down trip pattern and schedule exhibited in the Geoseps reference mission, utilization of Geoseps flexibility to provide multi-servicing missions over wide orbital sectors puts it in a more favorable light. Varying trip time with payload requirements, and focusing Geoseps on the servicing missions, maximizes its performance advantages and minimizes the unknown factors associated with long delivery times. To evaluate these effects a new transportation usage model was constructed for the platform program defined in Table 6.2-2. Platform deliveries and servicing schedules were held fixed as were the shuttle/tug volumetric constraints; but the extra payload capability and on-orbit life of the Geoseps were considered. The payload trip time relationships shown in Figure 6.2-2 were used in these calculations. The resulting shuttle/tug/Geoseps usages are summarized in Table 6.2-3.

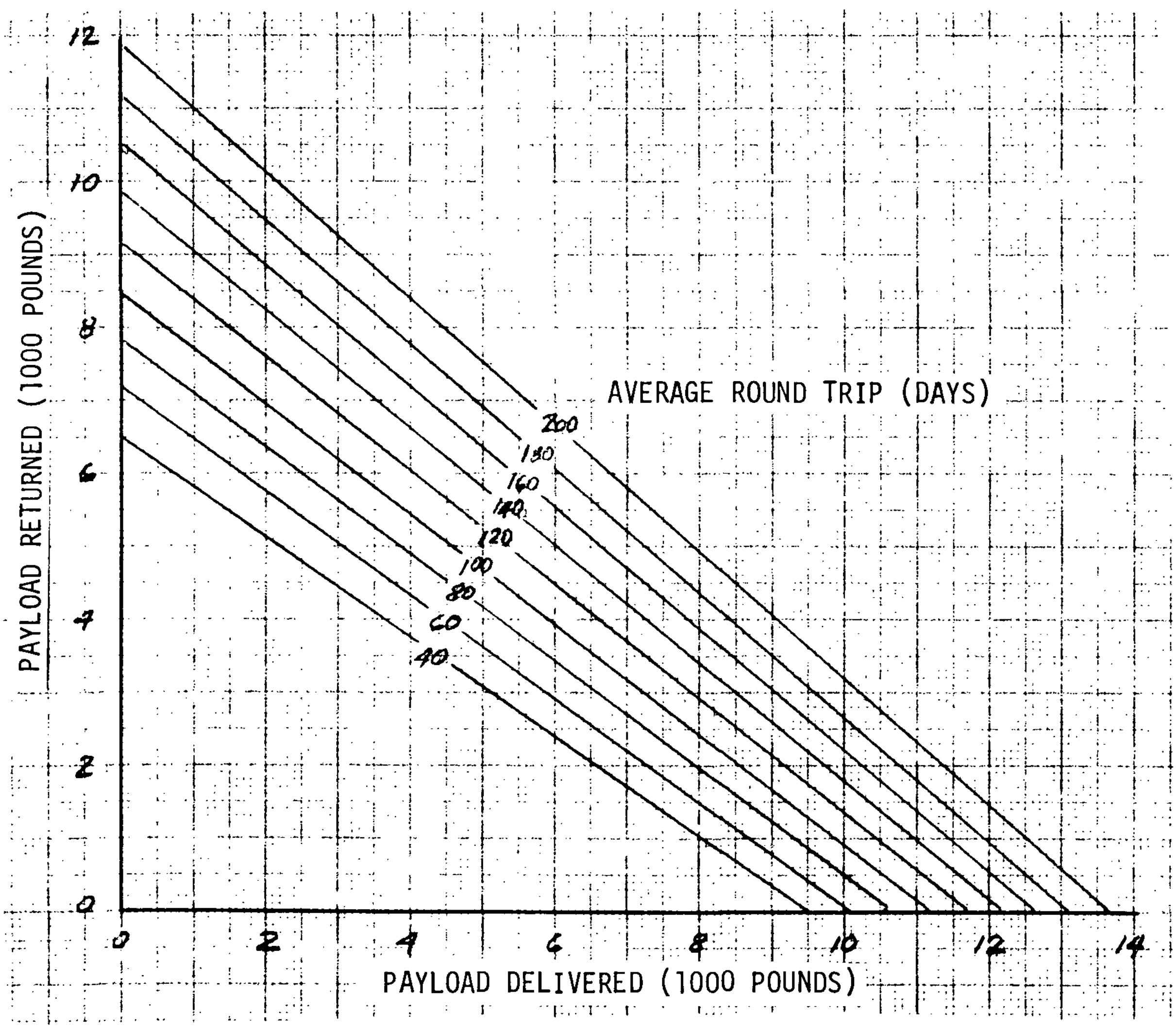

Figure 6.2-2. Trip Time Effects on Tug/Geoseps Payload Performance

Table 6.2-3. Platform Delivery and Servicing with Shuttle/Tug/SEPS

	81	82	83	84	85	86	87	88	89	90	Total
Single Tug Missions											
Delivery only	8	1	4		1	1					15
Service 2		1									1
Shuttle/Tug Flights	8	2	4		1	1					16
Geoseps Round Trips											
Delivery + 2 service			2								2
Delivery + 3 service			4								4
Service 3				1	1	1	1		1		5
Service 4					3		2	1	2		8
Service 5							1		1	1	3
Geoseps Operating Time (Days)	0	0	637	207	902	77	1068	126	987	246	4250
Shuttle/Tug Flights			6	1	4	1	4	1	4	1	22
Total Shuttle Flights	8	2	10	1	5	2	4	1	4	1	38
Total Deliveries	8	1	7		1	1					18
Total Service/Updates		2	8	3	15	3	16	4	16	5	72

*Three TDRS platforms delivered by Geoseps with ascent times of 80, 105, and 110 days.

In this model, all platforms except three TDRS configurations were delivered directly by the tug to minimize the total amount of shuttle launches. The three TDRS platforms were delivered in conjunction with multi-servicing missions. In all cases, a 300-pound weight penalty for payload exchange equipment was included. This weight was presumed to be attached to the Geoseps where it would have the least impact on overall transportation performance. The very high I_{sp} and relatively low structural mass fraction of the Geoseps make it much less sensitive to inert weight increases than chemical propulsion stages would be.

The analysis of the applicability of solar electric propulsion to geosynchronous platform programs was limited to general feasibility rather than detailed implementation. While further, more detailed analyses may reveal even more optimal ways of utilizing Geoseps, the foregoing usage model exemplifies the principal performance and cost advantages of Geoseps. In brief, 16 missions involving mostly platform deliveries were performed by the shuttle and tug alone. An additional 19 missions were flown with the shuttle/tug/Geoseps. These were mostly servicing missions, but included the delivery of three TDRS platforms. A total of 35 shuttle flights was required along with a cumulative Geoseps operating time of 4250 hours.

Hardware end item requirements which meet these program demands were determined. With a design "thrust life" of 536 hours per Geoseps, the 4250-hour total operating time requires a total of eight Geoseps. Two extra servicing units were required because of the long trip times. Four servicing units were required to meet the peak annual mission rate in the shuttle/tug/Geoseps usage model. This is two more than for the shuttle/tug only.

In the non-Geoseps program evaluations presented in Volume VI it was presumed that each unit has a 50-cycle mission life. Thus, the 56 missions required for the shuttle/tug program required two units. A worst-case assumption that separate units would be required for each Geoseps mission (in the peak flight years) was applied to the Geoseps case. The long on-orbit mission times with Geoseps, reaching six months in some cases, in conjunction with overlapping mission schedules and the time requirements for ground refurbishment of the servicing units, were the basis of this assumption.

Geoseps cost estimates presented in Reference 6-1 indicate nonrecurring costs to be \$35M or \$65M depending upon whether they were shared with the development of a planetary SEPS. Recurring costs are estimated to be about \$3M per flight or a total of \$15M per flight article. The total recurring costs for the eight Geoseps required in the sample program then becomes \$120M. Costs for the extra servicing units are approximately \$21M (2 units x \$10.57M each = \$21.14M). (Refer to Volume VI of this study.)

The effects of these cost influences are summarized in Table 6.2-4. The use of Geoseps results in \$121.5M savings in recurring transportation/service vehicle costs which is 17 percent of the equivalent costs without Geoseps. This is consistent with the 20-percent savings predicted in previous Geoseps studies (Reference 6-1). Net savings are dependent upon the method employed for sharing Geoseps development costs with other programs. The above data are for a platform program based on the baseline traffic model. Extrapolations to the new traffic model predicting up to \$300M savings in recurring transportation/servicing costs would be realized.

Table 6.2-4. Platform Program Cost Savings with Use of SEPS

Cost Factors	With SEPS	Without SEPS	Delta Cost ($ M)
Number of shuttle/tug flights ($12.5 M each)	35	56	-262.6
Number of Geoseps used up ($15.0 M each)	8	-	+120.0
RSU's required ($10.57 M each)	4	2	+ 21.1

Delta recurring cost	$ -121.5M
Geoseps development	$ 35 - 65M
Net savings	$ 57 - 87M

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6.3 CONCLUSIONS

The key findings of the foregoing analysis are summarized as follows.

- The Geoseps offers wide flexibility in the delivery and return of payloads to and from geosynchronous orbits. Various modes may be employed and trip time can be traded against payload weight.
- Geoseps offers long on-orbit life and performance flexibility for conducting widely spaced servicing operations and can provide up to 20 kilowatts of electrical power for servicing operations.
- Improvements in transportation system performance due to the above factors result in significant program net cost savings.

These advantages must be weighed against the following considerations.

- The platform programs defined in this study do not require the extra payload capabilities offered by Geoseps if a high-technology tug is available.
- If only a low-cost tug were available instead, either the Geoseps would be required or the configuration of some of the geosynchronous platforms would have to be modified to reduce their weight.
- The use of Geoseps is not compatible with the manned servicing mode.
- Long trip times with Geoseps compound the mission control and fleet operation problems associated with on-orbit servicing. The issue of scheduled versus unscheduled maintenance is involved.
- Long trip times also impose the requirement for additional servicing units to meet the defined flight rates (these are included in the net cost savings).
- The use of Geoseps adds the operational complexity of payload exchange operations.

It is concluded that the use of Geoseps for geosynchronous platform programs is feasible and offers significant potential cost savings as well as unique operational flexibilities, but not without several serious problems. The application of Geoseps should be further analyzed in terms of its being fully integrated in a space transportation system for long-term programs.

7.0 TRANSPORTATION REQUIREMENTS

The requirements imposed on the space transportation system by geosynchronous platform programs are discussed in this section. Both platform delivery and servicing missions are considered during the development of the requirements. The initial requirements are defined in terms of the shuttle/tug system dimensional and performance requirements. The functional interfaces are then discussed based on the data developed in Sections 4.0 and 5.0. The recommended changes to the space transportation systems are then defined.

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7.1 DIMENSIONAL AND MISSION PERFORMANCE REQUIREMENTS

An evaluation of the physical and performance compatibility of the space transportation system to conduct a geosynchronous program with the platforms, crew module,and remote servicing unit synthesized in this study is presented in this section.

The launch configuration dimensional characteristics of the geosynchronous platforms and servicing systems developed during the basic study are summarized in Table 7.1-1. The stowed platform lengths vary from 105 inches to 290 inches and the diameters from 140 inches to 168 inches. The overall lengths of the remote and manned servicing systems are 93 and 181 inches, respectively. The volume available within the shuttle cargo bay, with a reusable tug installed, is shown in Figure 7.1-1. As can be seen by comparing the capabilities shown in Figure 7.1-1 with the requirements shown in Table 7.1-1, all platforms and servicing systems are within the dimensional constraints of the shuttle/tug system. It can also be seen that the potential exists to combine the delivery of platforms with remote servicing missions using a single shuttle/tug launch. The potential constraint is the allowable payload center of mass in the cargo bay. All of the various combinations of platforms, crew module, service unit, and tug stages that conform to the five operational modes defined in Section 3.2 are within the limits of the baseline shuttle requirements.

The available payload volume within the shuttle cargo bay with a tug and a two-tier remote servicing system installed is shown in Figure 7.1-2. Adequate volume is available to combine a two-tier remote servicing system with any one of the platforms with the exception of the earth observations, solar astronomy, and stellar and X-ray astronomy platforms. Of these platforms, the stellar and X-ray astronomy platform could be combined with a single-tier remote servicing unit. Therefore, from a cargo bay volume standpoint only,all but two of the platforms can be delivered to orbit on a single shuttle/tug mission that could include servicing of previously delivered platforms. Delivery of the earth observation and solar astronomy platform requires a dedicated shuttle/tug mission. (Combined delivery/service missions are further constrained by the baseline tug payload capability as noted in subsequent paragraphs.)

The delta V's which the reusable tug must provide are developed in Section 3.3 of Volume III and are summarized in Table 7.1-2 for geosynchronous equatorial orbits. The resultant unmanned and manned tug payload capabilities for delivery only, return only, and delivery and return missions are shown in Table 7.1-3. These values must be significantly reduced if servicing operations are combined on the same delivery, round-trip,or retrieval mission. Figure 7.1-3 illustrates the payload capabilities for the tug configurations when the remote servicing unit is included on the unmanned mission, and the crew module is considered on the manned tug configuration. The remote servicing unit weighs approximately 1650 pounds; the crew module weighs 6050 pounds.

Table 7.1-1. Platform and Servicing System Dimensional Characteristics (Launch Configuration)

System	Length (inches)	Maximum Diameter (inches)
PLATFORMS		
Region I data relay	166	145
Region II data relay	185	155
Region III data relay	155	159
Region IV data relay	194	160
Domestic communications	194	152
International communications	194	152
Tracking and data relay	175	165
Navigation and traffic control	130	140
Earth observations	290	168
Solar astronomy	273	158
Stellar and X-ray astronomy	247	158
Plasma physics	105	166
High-energy physics	217	158
SERVICING SYSTEMS*		
Remote	93	160
Manned	181	148

* With two tiers

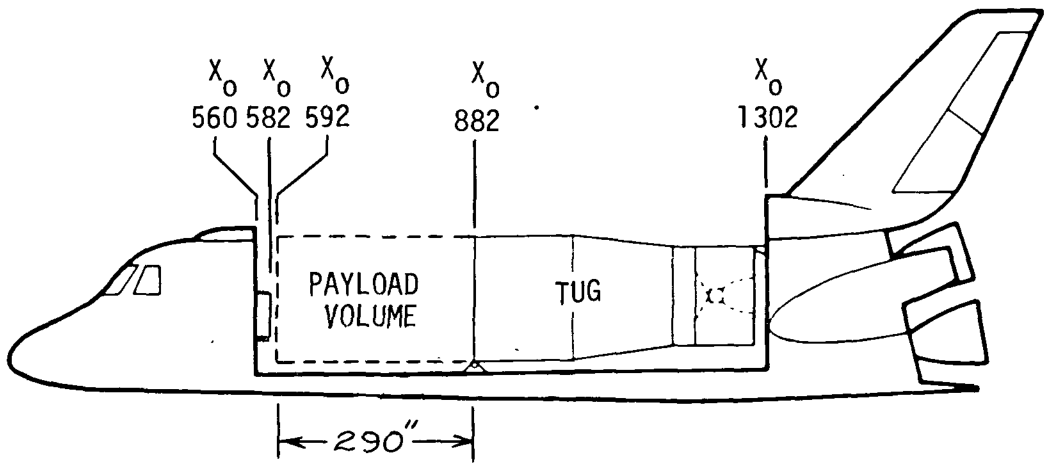

Figure 7.1-1. Shuttle Cargo Bay Payload Volume Available

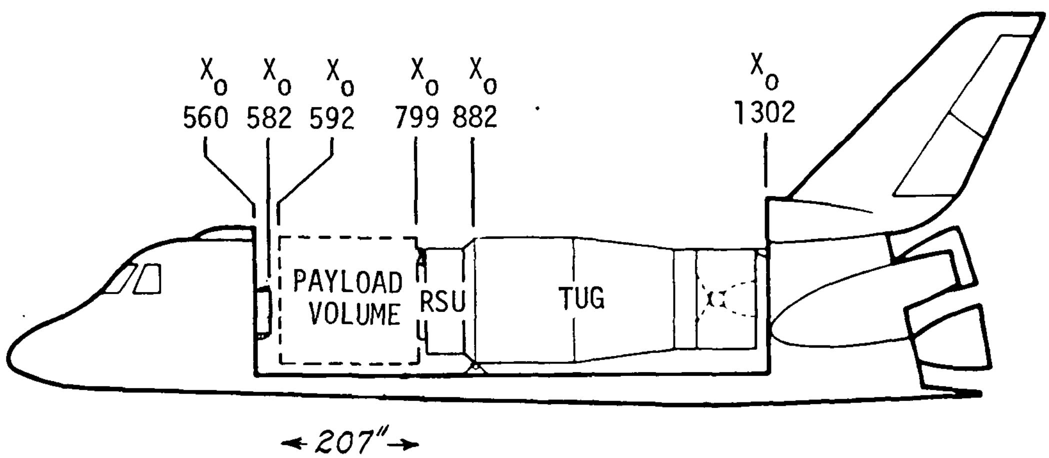

Figure 7.1-2. Payload Volume Available with Two-Tier Remote Servicing Unit

Table 7.1-2. Mission Delta-V Requirements
(Geosynchronous Equatorial Orbit)

Mission Event	Mission/Delta-V* (ft/sec)					
	Delivery Only		Return Only		Delivery and Return	
	MPS	APS	MPS	APS	MPS	APS
Separate from orbiter		10		10		10
Transfer orbit insertion	8040		8040		8040	
Gravity losses	260		260		260	
Midcourse correction		50		50		50
Geosynchronous orbit insertion	5847		5847		5847	
Gravity losses	10		10		10	
Orbit trim		30		30		30
Tug/payload separation		10				10
Rendezvous with payload			100	10	100	10
Dock with payload				15		15
Transfer orbit insertion	5847		5847		5847	
Gravity losses	7		7		7	
Midcourse correction		10		10		10
Parking orbit insertion	8040		8040		8040	
Gravity losses	24		24		24	
Midcourse correction		50		50		50
Backup rendezvous	100	25	100	25	100	25

*MPS - Main Propulsion System
APS - Auxiliary Propulsion System

Table 7.1-3. Tug Payload Capabilities

Mission	Payload Capability (lb)	
	Unmanned	Manned
Delivery only	8500	24,000
Return only	4650	10,000
Delivery and return	3225	15,000

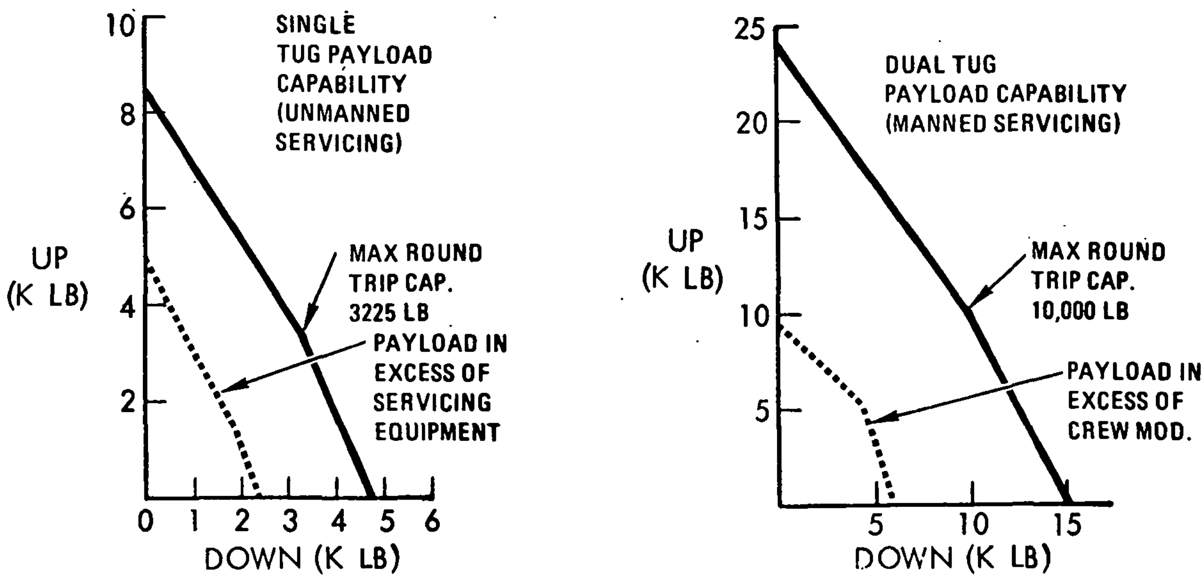

Figure 7.1-3. Servicing Configuration Payload Characteristics

Table 7.1-4 presents a summary of the compatibility evaluation of the payload capabilities of the two tug configurations and the platforms for delivery, delivery and return, return, and both manned and unmanned servicing/delivery missions. All platforms are within the delivery-only payload capability of the tug. However, only two data relay platforms, the TDRS, and the navigation and traffic control platforms are within the round trip capability of the tug. Four of the observational platforms (earth observations, solar astronomy, stellar/X-ray astronomy, and high-energy physics) cannot be returned by either tug configuration. These same four platforms are incompatible with a combined delivery/servicing mission with the unmanned tug. The manned tug configuration, which requires dual shuttles/dual tugs, can deliver any of the platforms in conjunction with the servicing of the platforms on the same mission.

Table 7.1-4. Tug-Platform Logistics Compatibility

MULTIFUNCTION PLATFORM	PLATFORM WEIGHT (POUNDS)	DELIVERY ONLY	DELIVERY AND RETURN	RETURN ONLY	DELIVERY AND SERVICE	
					REMOTE	MANNED
REGION I DATA RELAY	2759	X	X	X	X	X
REGION II DATA RELAY	2986	X	X	X	X	X
REGION III DATA RELAY	3274	X	-	X	X	X
REGION IV DATA RELAY	3835	X	-	X	X	X
DOMESTIC COMMUNICATIONS	4005	X	-	X	X	X
INTERNATIONAL COMMUNICATIONS	3609	X	-	X	X	X
TRACKING AND DATA RELAY	2651	X	X	X	X	X
NAVIGATION AND TRAFFIC CONTROL	2799	X	X	X	X	X
EARTH OBSERVATIONS	8496	X	-	-	-	X
SOLAR ASTRONOMY	6172	X	-	-	-	X
STELLAR AND X-RAY ASTRONOMY	5896	X	-	-	-	X
PLASMA PHYSICS	4102	X	-	X	X	X
HIGH ENERGY PHYSICS	8499	X	-	-	-	X

7.2 TRANSPORTATION SYSTEM INTERFACE AND SUPPORT

In this section the results of the interface design trades in Section 5.0 are summarized for the primary elements of the transportation system, the shuttle, and the tug.

SPACE SHUTTLE INTERFACES AND SUPPORT

The preferred concepts for shuttle-to-platform interfaces impose no unique requirements on either the baseline shuttle or platform. In all modes but one the interface is accomplished by means of the tug. In the one exception, the manned placement and servicing mission, the platform is independently mounted in the cargo bay. The shuttle interface is accommodated in the same manner as any other multipayload shuttle mission.

Shuttle Interfaces

The platform or service unit to shuttle interfaces for the unmanned mode are depicted in Figures 7.2-1, 7.2-2, and 7.2-3. There is no physical or structural interface between the platform and the shuttle in any unmanned auto-remote configuration because the platform or platform/remote servicing unit is cantilevered off the tug. The electrical/electronic interface is through the tug communication subsystem. The tug-to-shuttle interface is through a single connector located at the aft end of the tug in the base ring. The umbilical is not demated until the tug is activated, tug transferred to internal power, and the RF communication link established between the tug and the shuttle. The capability to control and monitor platform and/or remote servicing unit subsystems through the tug communication subsystem is verified prior to deployment from the shuttle.

The shuttle dual launch configuration to support a platform placement and manned servicing mission is depicted in Figures 7.2-4 and 7.2-5. A manned servicing unit without placement would delete the platform and the required physical and functional interfaces with the shuttle from the configuration depicted in Figure 7.2-5.

The method used in interfacing the crew-servicing module and the second-stage tug to the shuttle is the same as in the unmanned mission configurations. However, the shuttle containing the platform and the first-stage tug must interface with the elements independent of one another. The tug, with its tug to tug adapter, would interface with the shuttle in the standard manner at the shuttle through an interfacing cradle and retention mechanism standard for multiple shuttle payload missions. The electrical/electronic interface with the shuttle mission specialist station utilizes the standard platform activation and servicing umbilical connector.

UNMANNED MISSION MODES

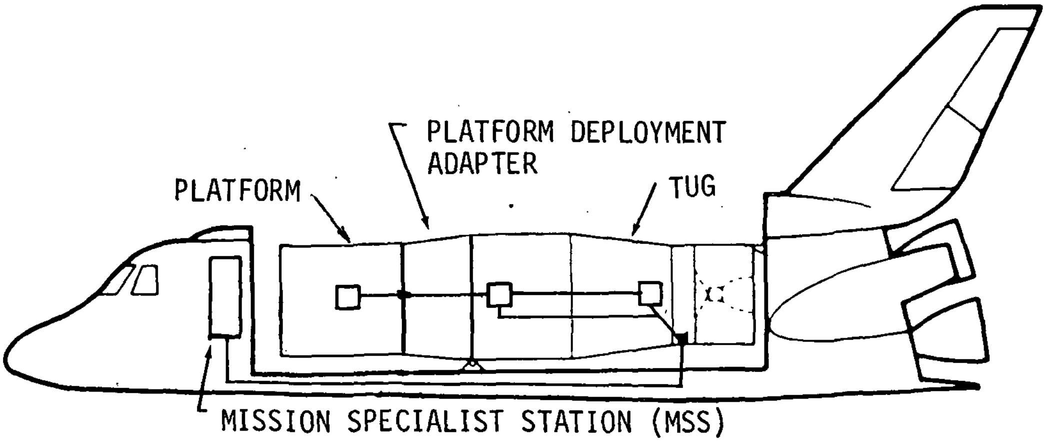

Figure 7.2-1. Platform Placement Mission

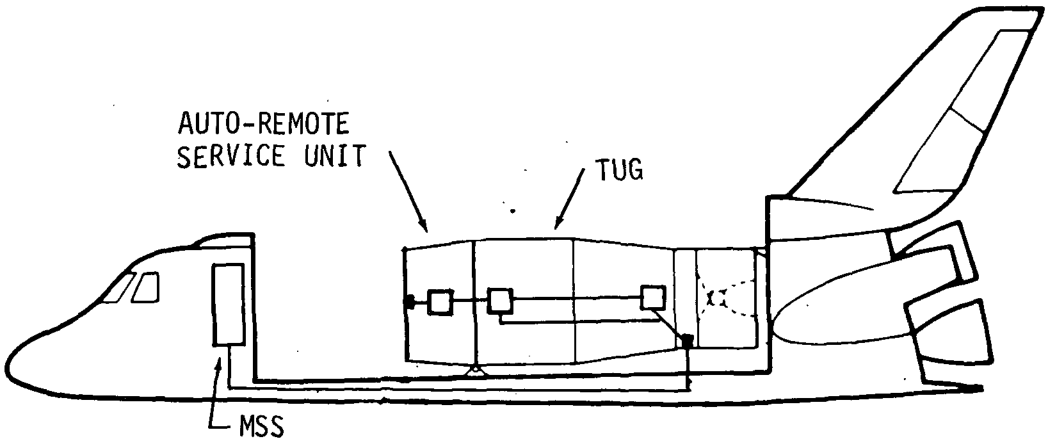

Figure 7.2-2. Auto-Remote Servicing Mission

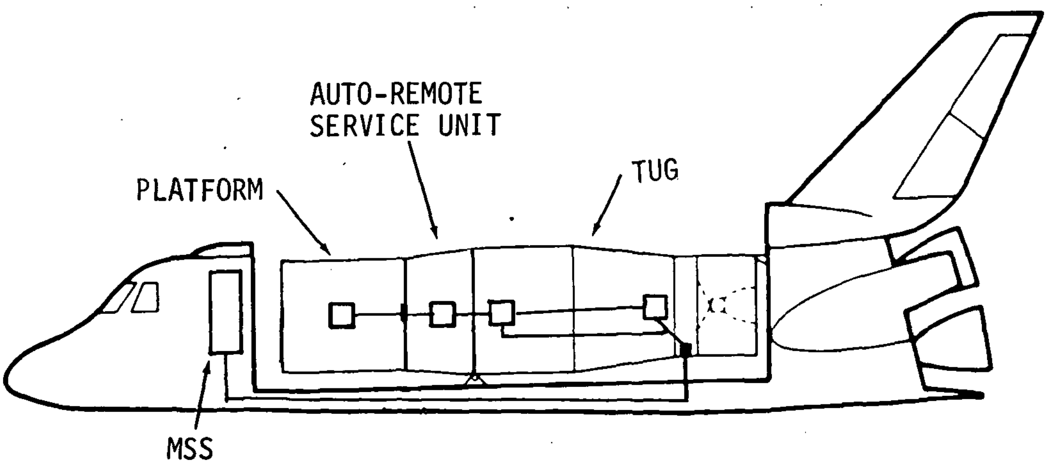

Figure 7.2-3. Placement/Auto Remote Servicing Mission

SHUTTLE DUAL LAUNCH - MANNED SERVICING
OR PLACEMENT/MANNED SERVICING MISSIONS

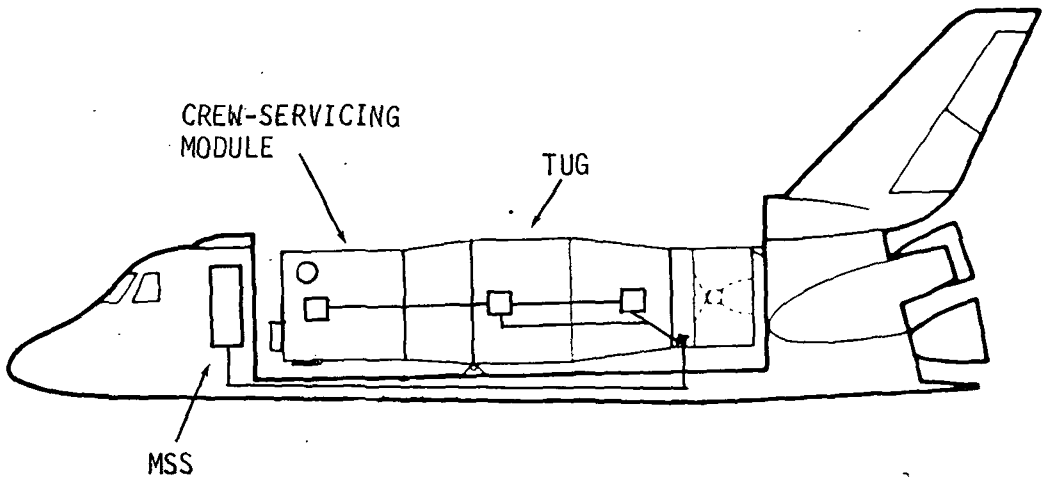

Figure 7.2-4. Shuttle Delivery of Crew-Servicing Module & Tug

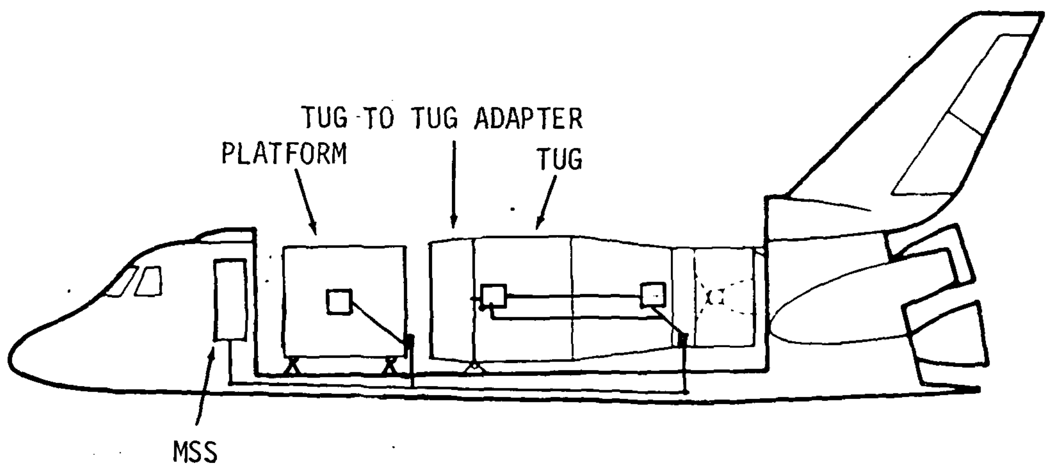

Figure 7.2-5: Shuttle Delivery of Platform & Tug

Shuttle Support Capability

The shuttle support to its payload is defined in this section. The term "payload" is defined as the tug, crew module, RSU, and/or platform configurations placed in the shuttle cargo bay for delivery to low earth orbit.

Electrical Power

The shuttle interfaces, controls, and distributes the power to the payload subsystems. The power control and monitoring is accomplished from the mission specialist station. The support characteristics are as follows:

Voltage: 28 vdc nominal

Power available during shuttle operational periods:

1000 watts average
1500 watts peak

Power available during shuttle coast period:

3000 watts average
6000 watts peak

Energy provided by shuttle: 50 kilowatt-hours

Controls and Displays

The shuttle's data management, control and display interface with the payload through the mission specialist station (MSS), the payload handling station (PHS), and the commander/pilot station.

Caution and Warning. The shuttle provides a caution and warning system for processing and displaying critical payload data. These data are displayed at the MSS and the commander/pilot station and are utilized in the determination of hardware aspects of the payload and the implementation of required corrective action. Critical payload parameters that are not hazardous to the mission are also displayed at the MSS.

Commander/Pilot Station. Payload master control circuit breaker, communications control (hardwire and RF), and master caution and warning are incorporated at this station.

Mission Specialist Station. Master caution and warning, payload-dedicated caution and warning, CRT display with keyboard control (both through shuttle computer support to payload), audio communications panel, and space for controls and displays to be provided by the payload for dedicated payload functions are an integral part of the mission specialist station.

Payload Handling Station. Support for payload deployment, docking/berthing, retrieval, maintenance, and remote operations through the use of remote manipulator arms is provided from this station. Controls and displays include

manipulator control, payload retention, cargo bay television video cameras, cargo bay illumination, audio communication, and caution and warning for payload operational items.

Data Management

Computer. In concert with the CRT display and keyboard control, computer facilities are provided by the orbiter for payload monitoring and control, checkout, fault isolation, and validation. The computer, with its software, provides the required data processing, command and control, data acquisition, and data display at the MSS.

Computer Capabilities

Word: 10,000 - 32-bit words
Speed: I/O 25,000 bps via data bus

Data Interface. Regional acquisition units (RAU's) in the cargo bay connect the data from the payload to the shuttle data bus and then to the stored program processor where the data are interleaved with the shuttle data. Commands for payload control from the computer are transmitted via the data bus to the payload command decoder. The primary assemblies and their functions are as follows:

1. Regional Acquisition Units (RAU's)
   a. Accepts analog, digital, and discrete signals from the payload.
   b. Samples and digitizes payload analog signals to the format required by the data bus and computer.
2. Payload Command Decoder Submit (PCDS)
   a. Accepts serial digital command from the computer with parity checking.
   b. Provides simultaneous command/stimuli generation with automatic calibration under computer command control.
3. Hardwire Interface

   Coax cables and wires are provided between the payload interface and the MSS for interfacing RAU's, PCD's, and dedicated control and display functions.

Communication

Voice. Two-way voice communication is provided between the payload bay and ground, crew stations and payload bay stations, and EVA links both to crew stations and ground.

Digital Data. Payload PCM data from RAU's in the payload bay can be transmitted to the ground through the stored program processor and S-band transmitter. Up to 25,000 bps of payload data can be transmitted to the ground by this method. Data from released payloads up to 2,000 bps can be received by the orbiter system for relay to the ground, or FCR transmission to the computer used for payload monitoring.

Television (TV). Two coaxial interfaces are provided in the payload bay for transmission of payload TV video signals to the ground, or to the video displays at the payload handler station.

Wideband Data. A hardwired interface is provided in the payload bay for transmission of realtime or delayed wideband payload data to the ground. This link accommodates up to 256,000 bits per second (bps) of digital data or provides wideband analog data. In either case, the payload provides the necessary equipment to ensure that the payload data are compatible with the shuttle transmitter.

Uplink Commands/Data. Inflight uplink information for attached payloads is routed to the computer from the S-band uplink command decoder. This information is relayed to the payload via a serial digital interface to the PCDS. In addition, this information can be relayed to release payloads (up to a range of 300 nautical miles) via RF, up to 2000 bps. Commands originated in the shuttle can also be transmitted to the released payloads by the same means. This link includes a command confirmation capability.

Table 7.2-1 summarizes the data transfer interfaces between the shuttle and its payloads. In the case of the platform all data transfer flows through the tug except in the unique case of the manned placement/servicing mission when the platform interface is directly with the shuttle.

TUG INTERFACES AND SUPPORT

Several changes/additions to the baseline tug are recommended. The ring frame docking concept is proposed rather than the probe and drogue. A 7-foot ring is required for auto-remote operations. The 5-foot ring that is compatible with the shuttle is required for manned operations. Additional fuel cell reactants are required to support combined placement and servicing of platforms in the unmanned mode. Because servicing missions can include changeout of power, data processing, and/or communications equipment of the platform, servicing operations must be monitored and controlled through the tug. This concept requires the addition of a modulator/demodulator in the tug communications system. Manned tug operations with the platform require access to the life support systems of the tug to maintain a habitable environment in the platform during servicing activities.

Table 7.2-1. Data Transfer Interface Summary

SIGNAL DESCRIPTION	HARDWIRE SHUTTLE/PAYLOAD INTERFACE	
	SHUTTLE	PAYLOAD
VOICE		
Intercomm.	Audio Center	Audio Comm Panel
TELEMETRY		
Interleave TLM	Stored Program Processor	Regional Acquisition Units
Direct TLM	Modulator/Demodulator	PCM Encoder
Wideband Analog	Wideband Xmtr	Freq. Division Max.
Wideband PCM	Wideband Xmtr	PCM Encoder or Recorder
TV Video	Wideband Xmtr	TV Camera
COMMANDS		
Attached Payload Commands	Computer/Keyboard	Payload decoder or dedicated payload controls
TELEVISION		
Camera Video	Video Display Unit	TV Camera
Camera Control	Video Control Unit	As/El Camera Actuators
	RF SHUTTLE/PAYLOAD INTERFACE	
VOICE		
Duplex	VHF Transceiver	VHF Transceiver
TELEMETRY		
Data	PCM Receiver	PCM Transmitter
COMMANDS		
Detached Payload	PCM Transmitter Signal Formatter	PCM Received Signal Processor Decoder
RANGING	Transceiver & Digital Range Gen	Transceiver - Range Tone Transfer Assembly

Unmanned Tug

The unmanned tug interfaces directly with the platform on placement missions and interfaces with the remote servicing unit on missions requiring auto-remote servicing. Both physical interfaces must be compatible with the ring frame docking mechanism as depicted in Figures 5.0-1 and 5.1-1 in Section 5.0 of this report. Figure 7.2-6 depicts the functional interface between the tug and platform for a placement mission. Figure 7.2-7 depicts the functional interface between the tug and the platform/servicing unit for an auto-remote placement/servicing mission.

External control from the tug ground control center is exercised through the tug communication subsystem to the platform data management subsystem. The modulator/demodulator (MODEM) demodulates the uplink carrier and routes the PCM serial-digital commands to the platforms DMS interfacing unit where the signal is decoded and sent to the DMS for execution. Conversely, data to be telemetered to the ground are processed to the platform DMS unit where they are encoded into a serial-digital PCM signal, routed to the tug MODEM for phase modulation on the downlink carrier. This RF signal is multiplexed on the tug downlink carrier to the ground control center via the space tracking and data network (STDN). This method of communicating with the ground is utilized by all three tug configurations.

Power support to the platform is provided by the tug electrical power subsystem (EPS) when its fuel cells are activated or when external power is provided through the shuttle umbilical. The control and monitoring of the power is accomplished by and through the tug DMS subsystem via the tug communication subsystem, or the shuttle umbilical. The unmanned tug provides approximately 700 watts of power and 50 kilowatt-hours of energy to support platform and RSU operations while attached to the tug.

Docking aids are located on the platform as depicted in Figure 5.0-1 in Section 5.0 to provide for proper alignment and the acquisition of data required to perform the docking operation. The location of the television and laser sensors on the servicing unit are depicted in Figure 5.1-1 in Section 5.0. The tug television downlink transmitter is used for both the docking television and the manipulator television support to servicing. The control of the docking and separation subsystem is through the tug-DMS subsystems.

Manned Tug

The manned tug is depicted in Figure 5.2-2 in Section 5.0. Conceptually, the crew quarters and platform servicing capability is integrated with the unmanned tug capability. Only the salient differences between the manned and unmanned interfaces and support to the platform will be discussed to avoid redundant coverage of areas common to both configurations.

The above referenced drawing depicts the electrical umbilical, laser radar, and visual docking sensor location required for platform docking aids and umbilical alignment with the off-center docking mechanisms. An adapter is provided to change the platform docking interface from the 7-foot-diameter ring frame to the 5-foot shuttle-compatible interface of the manned tug.

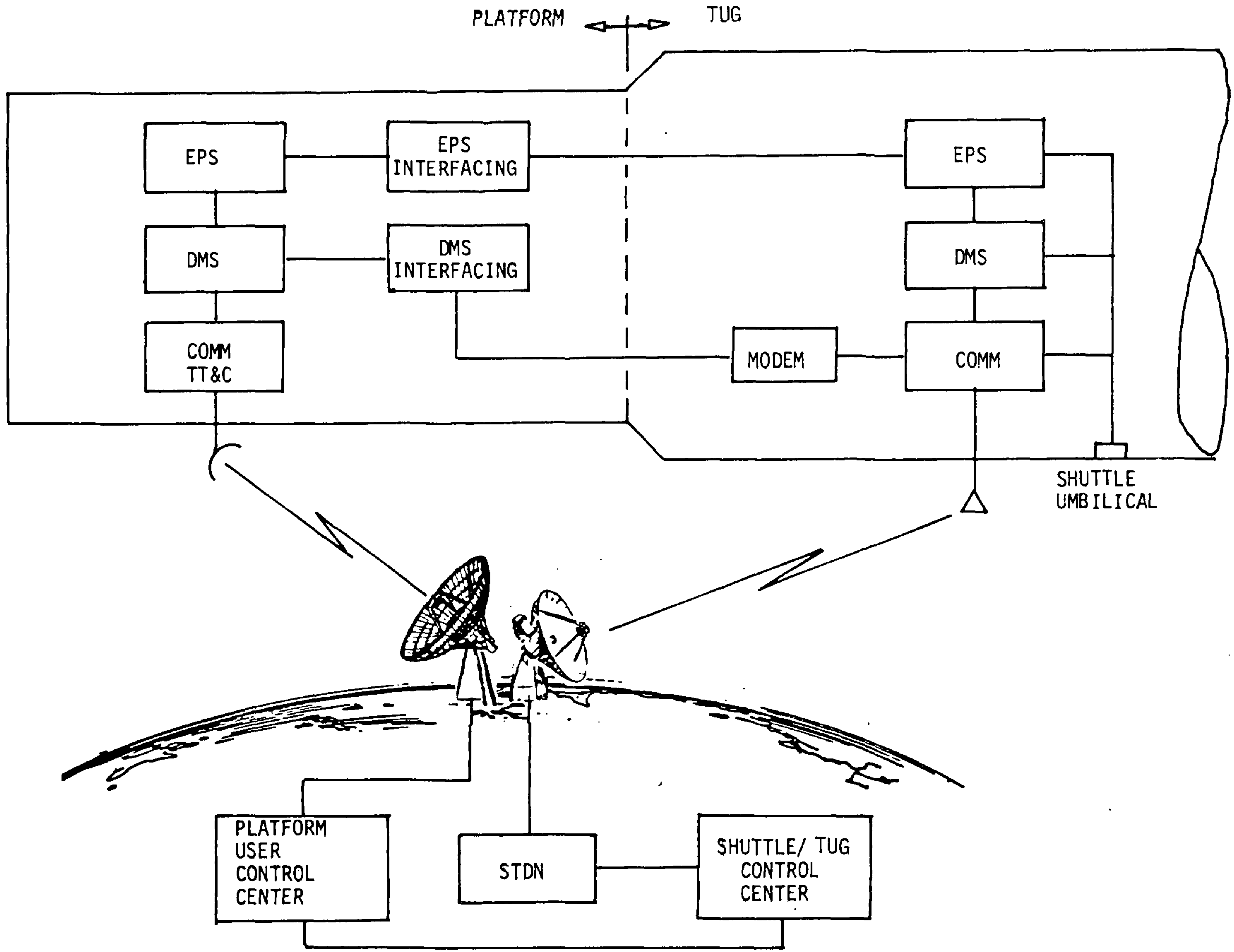

Figure 7.2-6. Platform Placement

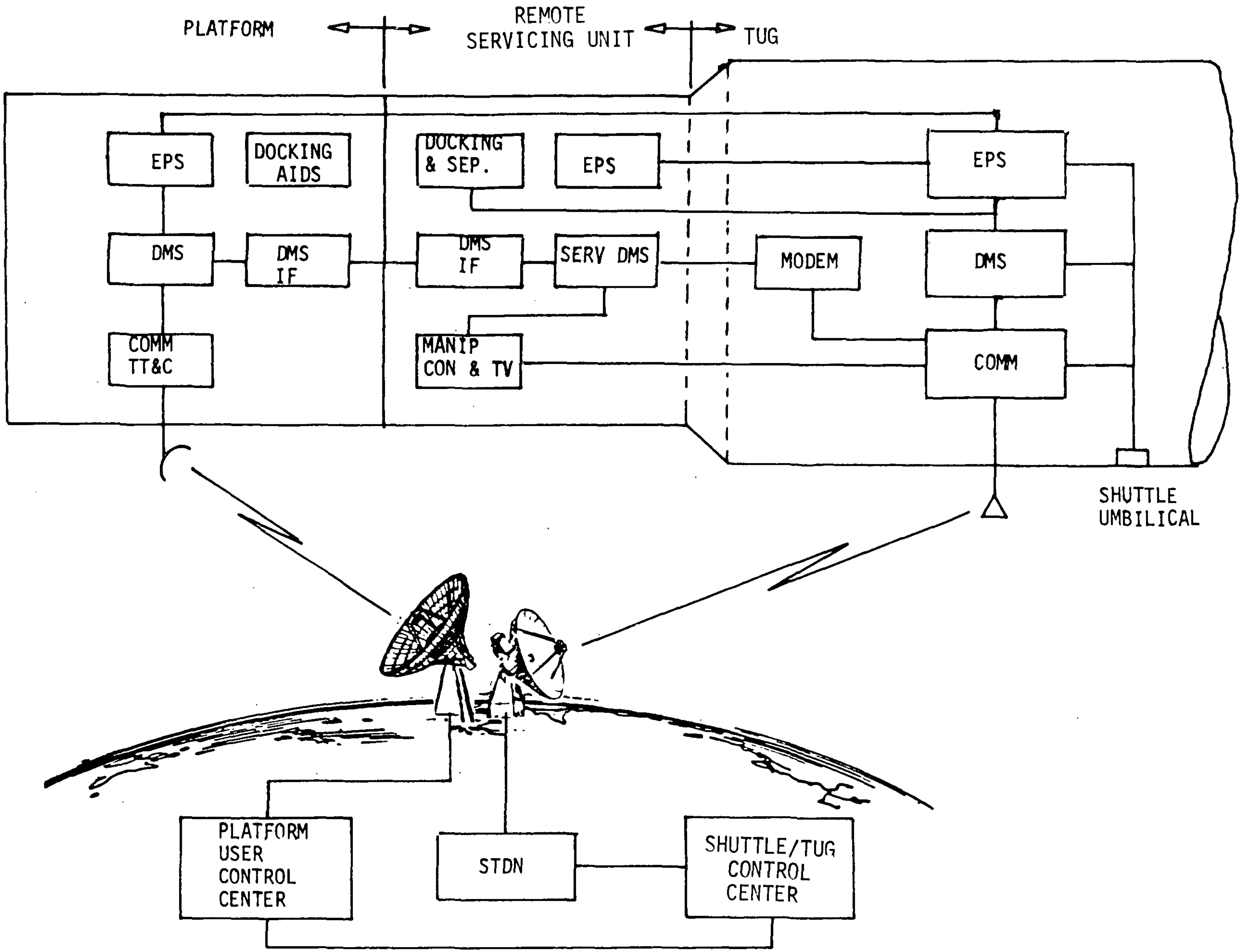

Figure 7.2-7. Auto-Remote Servicing/Placement

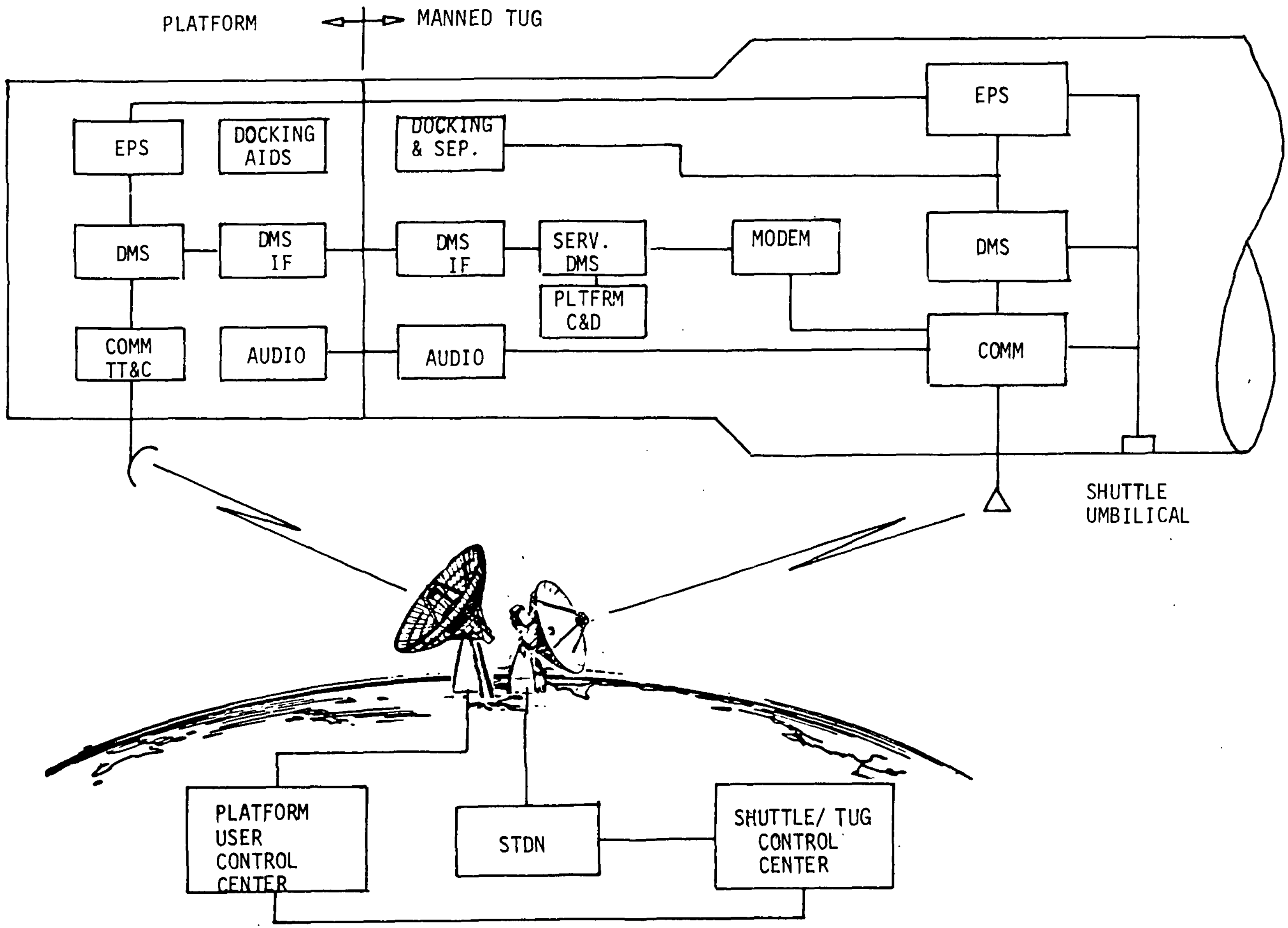

Figure 7.2-8. Manned Servicing/Placement

The manned tug provides the atmosphere for the pressurization of platforms to be serviced, and the equipment necessary for atmospheric control and circulation. Access to the baseline environmental and life support subsystem of the crew module is required to monitor and control the environment of the habitable volume of the platform during shirtsleeve servicing operations.

Figure 7.2-8 depicts the functional interface between the platform and the manned tug. The power, data, and control interfacing functions and methods are essentially the same as those for the unmanned tug interface. Life support functions and audio communications are the two additional functions required for the manned tug-platform interface. However, neither of these two functions interface with platform subsystems.

8.0 REFERENCES

2-1 Tug Operations and Payload Support Study, Final Report, SD 73-SA-0006, MA-04, Rockwell International Corporation, March 5, 1973.

2-2 Space Shuttle Baseline Accommodation for Payloads, NASA MSC-06900, June 27, 1972.

6-1 Feasibility Study of a Solar Electric Propulsion Stage for Geosynchronous Equatorial Missions, Final Report, SD 72-SA-0199-1 and -2, Rockwell International Corporation, February 23, 1973.